PROCEEDINGS I (A)

15TH ASIAN-PACIFIC WEED SCIENCE SOCIETY CONFERENCE

TSUKUBA
JAPAN
JULY 24-28
1995

Publishment of this Proceedings was partially supported by a grant-in-aid of the Tukuba EXPO'85 Memorial Foundation

PROCEEDINGS I (A)

15TH ASIAN-PACIFIC WEED SCIENCE SOCIETY CONFERENCE

TSUKUBA, JAPAN
JULY 24-28, 1995

THE ORGANIZING COMMITTEE OF
THE 15TH ASIAN-PACIFIC WEED SCIENCE SOCIETY CONFERENCE
1995

This volume of the Proceedings contains papers received by May 31 1995 from authors who have registered by that date.

Papers received on or after June 1, 1995 and those from authors whose registrations are received on or after that date will be published in the second volume of the Proceedings.

The order in which papers appear in this volume is similar to but not the same as their order of presentation in the program.

Printed by East Japan Printing Co., Ltd.
Tsukuba, Japan

ORGANIZATION

Organizer

The Organizing Committee of the 15th Asian-Pacific Weed Science Society (15th APWSS) Conference

Coorganizers

The Weed Science Society of Japan (WSSJ)
The Japan Association for Advancement of Phyto-Regulators (JAPR)

Supporters

Japan International Research Center for Agricultural Sciences, Ministry of Agriculture, Forestry and Fisheries (JIRCAS)
Food and Fertilizer Technology Center for the Asian and Pacific Region (FFTC)

Organizing Committee of the 15th APWSS Conference

Chairperson :	Ishizuka, K			
Vice-Chairpersons :	Hamaguchi, H.	Harada, J.	Ozawa, K.	Shibayama, H.
Secretary General :	Hyakutake, H.			
Secretaries :	Kobayashi, K.	Matsumoto, H.	Noritake, K.	Usui, K
APWSS Secretary :	Yamasue, Y.			
Treasurers : (Chairperson : Noguchi, K.)				
	Sato, E.	Takeshita, T.	Ueji, M.	
Planning : (Chairperson : Harada, J.)				
	Aizawa, H.	Asanuma, S.	Fukuki, K.	Hamada, K.
	Hyakutake, H.	Ichihashi, M.	Ichizen, N.	Kobayashi, K.
	Matsumoto, H.	Mizutani, M.	Morita, H.	Namazu, Y.
	Nemoto, M.	Noguchi, K.	Noritake, K.	Oki, Y.
	Sago, R.	Sato, M.	Shibayama, H.	Sugiyama, H.
	Takabayashi, M.	Takeshita, T.	Takeuchi, Y.	Ueji, M.
	Usui, K.	Yamane, S.	Yamasue, Y.	Yogo, Y.
	Yukimoto, M.			
Program : (Chairperson : Morita, H)				
	Aizawa, H.	Itoh, K.	Kobayashi, K.	Kurobane, I.
	Matsumoto, T.	Nemoto, M.	Noguchi, K.	Oki, Y.
	Omokawa, H.	Sago, R.	Shimizu, N.	Yukimoto, M.
Proceedings : (Chairperson : Sugiyama, H.)				
	Itoh, K.	Ito, M.	Kobayashi, K.	Kojima, K.
	Morita, H.	Nemoto, M.	Sago, R.	Sato, M.
	Ueji, M.	Yogo, Y.		
Excursion : (Chairperson : Noritake, K.)				
	Asano, H.	Ikai, T.	Kamoi, M.	Monma, K.
	Namazu, Y.	Takeshita, T.	Yogo, Y.	
Venue and Exhibition : (Chairperson : Sago, R.)				
	Aizawa, H.	Ikeda, M.	Isokawa, T.	Jikihara, K.
	Matsumoto, H.	Noritake, K.	Uno, Y.	Yamane, S.
	Yasui, K.	Yogo, Y.		

Fund Raising Committee

Chairperson :	Ishizuka, K.			
Vice-Chairpersons :	Hamaguchi, H.	Harada, J.	Hyakutake, H.	
	Ozawa, K.	Sato, E.		
Advisers :	Chisaka, H.	Konnai, M.	Kusanagi, T.	
	Matsunaka, S.	Miyahara, M.	Yoshizawa, N.	
Secretariat :	Kobayashi, K.	Matsumoto, H.	Noritaka, K.	Usui, K.

CONTENTS

I (A)

Plenary

Symposium

Concurrent

Mode of Action of Herbicides in Low Rate

Allelopathy

Resistance to Herbicides

Mode of Action of Herbicides

I (B)

Wild and Weedy Rice

Physiology and Ecology of Weeds

Ecology of Weeds

Application and Formulation

Socio-Economical Effects of Technical Innovations in Asian Agriculture

Kamphol Adulavidhaya
Thanwa Jitsanguan

1. Introduction

Until this point in time, the Asian agriculture has been developed through a very long history and experience. By and large, agriculture is considered the birth source of most Asian nations. With the similar resource endowment in the region, the majority of each country was and is still engaged in one way or another in the agricultural sector. Production pattern, input use, price and market problems, and recently environmental impacts among farms in the Asian region are not significantly different. Trend is shown in many ways, however, that agriculture is now facing many challenges from internal factors of the agricultural sector itself and external factors from various competitive non-agricultural sectors. The global promotion in trade liberalization has turned around the structure of agricultural production in every countries. Direction of agricultural development in the coming century is then one of the key issues that will definitely affect the overall welfare of Asian population.

Since the market economy becomes more competitive both at the regional and global levels, a lot of significant changes can be anticipated in agricultural production of Asian countries. Structure of crops and animals as well as production system will need to be re-considered from all aspects. Mobilization of factor inputs especially capital and labor from the agricultural sector to other economic sectors with relatively higher growth rate has affected all farming patterns and systems. Farmers should be ready in re-adjusting their cropping pattern and input use according to such changes. Substitution among factors of production for the least cost combination will play important role in determining the sustainability of agricultural production. The combination of factors and inputs used should not only be feasible from the production and environmental conditions but should satisfy the economic and social conditions as well.

Technical innovation in agriculture is considered a part of solution to those emerging problems. Despite there is unclear definition and scope, appropriate technology has been a key issue in Asian agriculture for a long time. Different technologies applied to agricultural production simply implies the unique characteristics of resource and input use, production cost, farm profit, and environmental impacts created. Farm technology is supposed to be effective, low cost, and with less external impacts. Induced agricultural technology should particularly lead to higher farm productivity. On the other hand, farm technology can also affect the farmers themselves in terms of labor employment, time allocation, income generation, and natural environment of farm households. Due to the existing open economy system, effects on these socio-economical factors can be again expected at both within and beyond the farm gate level. Innovation of any farm technology, therefore, should be applied with great care and already considered from all relevant aspects.

This paper will discuss the consideration of effects from technical innovations on socio-economical factors of the Asian agriculture in general.

Kamphol Adulavidhaya, Ph.D.(Ag.Econ), is Professor in Agricultural Economics and the President of Kasetsart University.

Thanwa Jitsanguan, Ph.D.(Econ), is Assistant Professor in Agricultural Economics and Chairman of Resource Management Program, Kasetsart University.

2. Asian Agriculture in Dynamic Economy

In many senses, agriculture is usually the symbol of most developing countries including those in the Asian region. Agriculture-based countries also implies the countries with low productivity and significant dependence on primary products. The vast majority of Asian population has lived and worked in the rural sector. This human resource allocation suits very well with other natural resources especially land.

The Asian countries(*) has the total land of 2,121 million hectares with 2,831 million population in 1990. At least 18.6 percent of total land was agricultural land in 1990 and the percentage had been almost constant since 1980. Without China and Mongolia, such a proportion can immediately be increased to 31.7 percent. As compared with 18.6 percent of total land, more than 60.9 percent of Asian population still resided in agricultural sector in 1990 of which the proportion was reduced from 67.1 percent in 1980. During 1980-90, while agricultural land can be expanded at only 1.6 percent, the total agricultural population increased at 9.8 percent.

These figures simply show that the pressure of population on land resource still remain significantly in Asian agriculture. With limited country area, intensification of agricultural land use by any how is most likely inevitable.

On the other hand, the average GDP contribution from the agricultural sector to an economy of Asian country was found reduced from 39.8 to 26.8 percent during 1965-90. The changing situation was similar throughout every Asian countries. This is mainly resulted from the relatively higher growth rate of non-agricultural sectors, especially industrial and services, which has dominated the economic development direction of Asian countries since 1960s. Processing of raw materials, manufacturing of high-tech electronic products, and tourism have been on the list of top export earning sectors.

The growth rate during the past three decades of the agricultural sector in Thailand, for an example, was approximately 4 percent as compared with those of non-agricultural sectors 12 percent. As a consequence, the Thai agricultural GDP was then reduced from 35 to only 12 percent.

The relatively higher growth rate of non-agricultural sectors was basically the success of promotion in forward-looking policy. Export promotion strategy has been widely adopted and adapted in Asian countries since 1960-70. Many economic incentives in terms of production subsidies and tax rebate for foreign investment are provided for those export-oriented industries. The successful case of "Gang of Four" including Rep.of Korea, Hong Kong, Taiwan, and Singapore was forever cited as the blueprint for those who wanted to be the Newly Industrialized Countries (NICs).

Agriculture, on the other hand, has been usually given low policy priority. Fluctuating price and world market conditions are often seen unfavorable to agricultural production. Moreover, the majority of Asian agriculture still depends upon the natural factors particularly rain and soil fertility. Environmental impacts, natural resource degradation and food safety also appear as the new constraints to agriculture. The traditional expansion of "quantity" production is now converted to concentrate relatively on the "quality" production.

Change in the structure of GDP contribution is in fact related to economic development direction of Asian countries. Such combination trend of GDP really implies that most Asian countries are moving from agriculture towards the industrialization. In other words, they are shifting from the relatively low-value production to the relatively high-value production. This is said to be the typical pattern of economic development process for most developing countries. The rate of transformation in economic structure, however, seems to be faster during the recent years. Agricultural sector in the dynamic economy of Asian countries, therefore, is generally considered in the uncertain situation. Sustainability of the agricultural sector is now one of the most critical issues in Asian countries.

(*) The Asian countries in this paper cover 19 countries including Bangladesh, Bhutan, Burma, Cambodia, China, DPR Korea, India, Indonesia, Iran, Laos, Malaysia, Mongolia, Nepal, Pakistan, Philippines, Rep. of Korea, Sri Lanka, Thailand, and Vietnam.

3. Technological Change and Innovation

If one tries to understand more deeply the pattern of agricultural transformation in Asian countries, he might have to consider the technological change and innovation at farm level. Induced agricultural technology from the successful "Green Revolution" during 1960s was apparently the main factor responsible for changing in pattern of agricultural production. Innovation of high yield variety, pesticide and insecticide, chemical fertilizer, and farm mechanization were influential inputs to increase farm productivity and to change farming system. Research from the International Rice Research Institute (IRRI) in the Philippines, for an example, was totally to support the technical innovations in Asian agriculture.

One can also observe that farming in Asia has been passing at least three major stages of its development according to level of technology.

The first and most primitive stage is the subsistence farming where all farm produces are only the staple crops such as rice and vegetables especially needed for household consumption. Based upon the natural factors such as land and rain, farm productivity is usually low and subject to all risk and uncertainty. Natural environment at farm level, however, is relatively well preserved. Labor is predominantly the major factor of production together with some simple capital tools.

The second stage of farm production might be called the diversified farming since part of farm produces is grown for self-consumption and part for market demand. Staple crops no longer dominate the farm output since new cash crops such as fruits, maize, and soybean as well as small-scale animal husbandry are introduced into farm. Despite labor still remains the major ingredient in farm production, technology in terms of high-yield variety, fertilizer, pesticides are also applied in farm.

The third and final stage of farm production is the specialized commercial farming. This advanced farm production will specialize in cultivation of one particular crop in order to serve for the market demand either domestically or internationally. Technological progress and scientific research play a major role in stimulating higher productivity in this farm. The farm depends less upon natural resources such as land, rain, and labor. Capital formation in terms of labor-saving technique of production, such as mechanization and chemical application, is the key element to enjoy the "economy of scale" or reducing an average unit cost with larger farm size. Some of the large-scale specialized farms in Asian region are also owned and operated by the multinational agribusiness companies.

Many characteristics can be mentioned to distinguish each stage of such development in farm production. Technical change and innovation, however, appears obviously as the key criteria. Change in the capital-labor ratio (K/L) in production technique can be employed to indicate the overall figure for each stage of farm evolution. Increase of the K/L ratio implies that labor factor is more replaced by capital factor from technical innovation. Accordingly, the K/L ratio is supposed to be relatively low for the subsistence farming and relatively high for the commercial farming.

There are at least two major sources of technical innovation in agriculture. Mechanical innovation in terms of labor-saving technology, such as tractors and other farm machineries, has been proved since its introduction that it is very effective for the extensive farm production, large-scale farming, or where farm labor is scare. On the other hand, biological and chemical innovation in terms of land-augmenting technology can also improve the intensity of existing land use by raising yields per area. Biological innovation such as hybrid seeds and chemical innovation such as fertilizer, pesticides and insecticides can be employed for both the large- or small-scale farming.

As the major technical innovation in agriculture, it should be noted that the use of tractor and chemical fertilizer in Asian countries had been increased during 1980-90 by 5.2% and 6.8% respectively. Of the same region, an average application of fertilizer per hectare was 128 kgs in 1990 as compared with that of Japan, 400 kgs per hectare.

Since these two types of technical innovation are almost totally different, application of each technical innovation may depend upon many factors. Size of farm, availability of farm labor, and conditions of land such as soil structure and land slope are probably the major determinants in this regard. In order to solve the same problem in farm production such as control or eradication of weed, each type of technical innovation can simply create dissimilar effects on natural resources, environment, or even human resources. The effects are considered critical in case of Asian agriculture which farm conditions are very diverse and the sector is now undergoing the rapid change in social and economic structure.

4. Effect of Technical Innovation on Socio-Economical Aspects

Since the Green Revolution, transformation from the subsistence to the highly commercial farming system has been simply considered the success case of Asian agriculture. Not only as the main source of food production, surplus of agricultural commodities still serves as the important source of export earning. Such significant increase of agricultural production is inevitably resulted from technological development. Increasing farm productivity and decreasing production cost from the "labor-saving" mechanical technology and the "land-augmenting" biological and chemical technologies can be cited in general. Technical innovation, however, has also created various external effects on the farm sector in addition to such success. Among them, the socio-economical effect seems to stand at the front line.

In fact, relationship between socio-economical conditions and technical innovation can be considered from various viewpoints. Both positive and negative socio-economical effects can be mentioned as the results from innovation of different agricultural technologies and under different farm conditions.

These socio-economic effects are as follows.

Effect of Labor Employment

Effect on labor employment from technical innovation is very obvious since there is factor substitution between capital and labor. Technical innovation in terms of labor-saving factor can simply result in significant unemployment from that labor being replaced by capital factor. Farm machinery such as large tractor can be used in lieu of labor for extensive farm activities starting from land preparing, weeding, plowing, planting and harvesting. As a consequence, labor employment in farm, especially the unskilled, will have to be declined. The situation in turn will help induce the intersectoral migration between agricultural and non-agricultural sectors or the rural-urban migration pattern of farm labor. Increase of social problems of farm labor in the urban sector such as full unemployment, illegal or immoral employment, lack of residence, traffic congestion, and insufficient health care can all be expected.

Not only domestic migration within each country, migration of farm labor can even take place in the international level. Legal and illegal migration among Asian countries has been significantly observed during the recent years. In addition to wage differential, the main cause of international migration is also the excess supply of labor in some countries which is now substituted by capital factor in farm production. In this regard, migration of farm labor can also reflect to some extent about the level of technical innovation in the agricultural sector of each Asian country. For example, farm labors from Thailand have migrated to Taiwan and Japan while they are being replaced by farm labors from Burma and Cambodia.

Accordingly, the success of technical innovation in agricultural sector is often made at social cost of non-agricultural sectors of the same economy or even the rest of the world.

Effect on Time Allocation and Non-Farm Income of Farm Households

However, the effect of technical innovation can be also considered in terms of time re-allocation of farm households. Since most technical innovation is the time-saving factor, substitution of capital for labor will simply result in more leisure time for farm labor as well as all household members. Given the constant farm income, availability of more leisure time is thus part of the well-being of farm households.

Regardless of intersectoral migration, more time available for farm labor can also suggest additional non-farm income possibly generated at farm households. There are many non-farm activities that can be mentioned as the positive effect of time-saving technical innovation such as household crafting industry, food processing industry, or small-scale business in the rural community. Time re-allocation for farm labor and household members as a result of technical innovation then can become the supplementary source of the total household income.

Effect on Net Farm Income

There is always an assumption that technical innovation in agriculture will bring the higher productivity and lower production cost. However, the assumption is proved in reality that it is not always true. Assuming small-scale farm size with abundant farm labor such as in many parts of Asian agriculture, the labor-saving technical innovation is sometimes regarded as anti-developmental factor. This is because the introduction of heavily mechanized farming techniques can significantly create the unemployment of farm labor without necessarily lowering per unit cost of farm production. In other words, increase of capital factor in terms of labor-saving technology for the small-scale farming may not always lead to the cost-saving. In stead, cost per unit of farm production with technical innovation can become even higher and finally result in declining net farm income or even net loss of farm business. With economic disincentive from farm production, migration of farm labor out of the agricultural sector will be even at the faster speed.

The case can simply be found in the rural areas of Asian countries where most farmers are relatively uneducated and own small-scale farms. Effect of excessive commercialization and ineffective agricultural extension program can help worsen the situation by introducing inappropriate technical innovation.

Effect on Natural Environment

It is obvious that natural resources and the environment have the strong link with technical innovation in agriculture. Mechanical innovation can directly create top soil loss, heavy soil erosion and reduce soil moisture during the stage of land preparing and weeding while biological and chemical innovation will damage the natural balance of biodiversity and pollute the surface or underground water. With intensive chemical use in farm production, degree of food safety can also be expected to decline. All of these environmental impacts will then affect the welfare of farmers, the rural society, and every consumer in the economy.

In order to prevent, or to solve if possible, such environment problems, much of farm production cost will have to be increased. Still, it can be expected that not all of environmental impacts created by technical innovation will be completely recovered. Part of the complicated natural environment, once destroyed, will never be the same again or may have to take a very long period of time to heal itself. Also, despite the cost of environmental impact from agricultural production is significant, most Asian countries still seem to ignore or underestimate the problem.

Effect on Structure of Rural Community

The ultimate effect of technical innovation on socio-economical aspects is on the structure of rural communities in Asian countries. Substitution between capital and labor not only deals with issues of production technology, production cost, farm income, and degradation of natural resources and environment, it can also come to weaken the structure of rural community as a whole. As the final consequences from unemployment, rural-urban migration, and unpleasant environment, many rural communities in Asian countries are commonly left behind with broken farm households with elderly and children. Some rural communities are even completely abandoned. Economic incentive from higher wage rate and better job opportunity in other sectors of the country has easily attracted a lot of farm labors during the on-going information age.

Fragile structure of rural communities and so weakening rural sector in Asian countries is then another major social cost of agricultural development in terms of technical innovation.

5. Evaluation of Technical Innovation in Agriculture with respect to the Socio-Economical Effects

In considering the success or failure of technical innovation in agriculture, one therefore has to compare the total benefit and total cost directly or indirectly involved. Technical innovation does not only imply the increase of capital-labor ratio in the production process, the increase of farm output, and the decrease of production cost. It also suggests the change in time allocation of farmers, decline in farm labor employment, and then change in farm household as well as social structure. As also consequences from the production procedure, technical innovation in agriculture may also create environmental impacts from both the production and consumption aspects.

Basically, benefit from technical innovation may simply be measured in terms of incremental farm productivity, and then incremental farm return, from the production with and without technical application. Cost, on the other side, is even more simple since it can be measured in terms of additional cost of technical application. With evidences in higher productivity and lower cost, the technical innovation in agriculture is assumed to be justified from the technical point of view.

However, if all socio-economical effects are taken into consideration, the benefit and cost of technical innovation has to be re-considered. External benefit and external cost generated from technical innovations should be added into the typical measurement of benefit and cost. Despite it is extremely difficult to estimate the complete value of external effects, socio-economical effects can serves as the good examples of external benefit and cost potentially induced by technical innovation. From those mentioned earlier, external benefit may include effect on leisure time and non-farm income while external cost may include effect on labor employment, net farm income, natural environment, and rural community structure.

Accordingly, it might be more appropriate to introduce the <u>social evaluation</u> in replacing the <u>technical evaluation</u> or <u>private evaluation</u> for technical innovation. Such social evaluation will include all the physical, socio-economical, as well as environmental aspects of technical innovation. Appropriateness in technical aspect does not always indicate the feasibility of socio-economical and environmental aspects. With these new evaluating approach, the usual justification about technical innovation in agriculture can possibly be changed.

With respect to the socio-economic effects, technical innovation in agriculture is not only to increase farm productivity or decrease production cost but to change part of farm households and the whole structure of rural community. The technical innovation can then affect the welfare of an individual farmer, his farm household, or the rural community. The general socio-economical effects can even come across the agricultural sector to other sectors of the country. In this respect, technical innovation is not considered only the issue of agricultural production per se but also considered the issue of farm and rural development at the same time. Consideration for the adoption of any technical innovation will definitely go beyond the farm gate and boundary of the agricultural sector.

6. Rationale for Technical Innovation in the Future: Consequence of Socio-Economical Change

Despite the social evaluation of technical innovation might be somewhat complicated and sound rather pessimistic for farmers in Asian countries, the need for development in technical innovation is still obvious and significant. Rationale for the need of technical innovation in agriculture can be ranged from the change of "micro" socio-economical conditions until the change of "macro" international policy.

In other words, change in socio-economical conditions can be considered as both the consequence and the cause of technical innovation in Asian agriculture.

Rationale of technical innovation from the micro prospect

Effect of market conditions

It can be noticed that many Asian countries can naturally produce and trade in similar crops and animals. The excess supply of the same agricultural commodity in this region is one reason to explain the declining price and then lower farm income of the farmers. Agricultural production in the future should therefore concentrate more on the issue of "quality" production in stead of the typical "quantity" production.

Moreover, the socio-economical conditions such as income level, education, employment, lifestyle, and taste of consumers can help determine the production. As consequences of socio-economical change especially higher income effect in many Asian countries, "quality" of agricultural commodities will potentially be more demanded and becomes one of the key factors to differentiate the price and market share. The Asian agriculture should therefore be more aware of the quality production. Competition for the quality production in agriculture will require a number of factors including some "green" technical innovations which can produce safe foods with the least environmental impacts. Research and development regarding environmentally sound technical innovation will be of great need for Asia in the future.

The suburb agriculture

Importance of technical innovation in agriculture as related to the socio-economical change can also be seen from the case of suburb agriculture.

The suburb agriculture simply imply the agricultural production at locations adjacent to the urban areas or the large cities which result in the scarce supply and higher opportunity cost of land and labor. Quantity, quality, types, and time of agricultural production are directly affected by strong market force of the urban sector. In such areas with increasing shortage of labor such as the suburb around capital cities in Asian countries, for an example-- small provinces surrounding Bangkok in Thailand, Manila in Philippines, and Jakarta in Indonesia, technical innovation is prominently the solution in continuing the farm production. According to better communication and information system, farm labor in the suburb areas will easily look for the alternative employment outside the agriculture. This finally result in the increase of production cost from higher wage rate in order to attract the increasingly scarce farm labor.

In case of suburb agriculture with scarce labor supply, mechanical innovation in terms of labor-saving technology can potentially bring down the per unit cost in the large-scale commercial production according to the "economy of scale" principle. In case of limited land resources, land-augmenting technology in terms of biological and chemical innovation can also raise farm productivity in response to the increasing demand for food and agricultural products of the urban areas.

Rationale of technical innovation from the macro prospect

Effect of trade liberalization

As an indirect effect of the global socio-economical change, technical innovation is also involved with the international policy. The current trend of trade liberalization has made commercial agriculture of Asian countries now in the process of re-structuring the pattern of agricultural production to suit the free-trade market system. With disappearing protection and subsidy measures in international trade, comparative advantage of agricultural sector in the future will rely more upon the actual cost of production and improved farm productivity. Development of agricultural technology and effective production planning will be the key macro factors for the success of agriculture in the future.

According to such expected situation, technical innovation appears even as the more important factor in effectively planning the agricultural production in relation to the appearing liberalized trade policy. Encouragement or discouragement for specific crop production according to liberalized trade policy will need to be supported by appropriate technological factor. With better research and development, technical innovation can potentially help produce crops and animals according to the conditions of supply and demand in the domestic or international market

Factor substitution

Generally, rationale of technical innovation in the future can also be mentioned as the factor substituted for resource scarcity in agricultural production. It is generally realized that agricultural resources are now declining both in terms of quantity and quality. In spite of the fact that supply is physically limited, land suitable for agricultural production is declining from being converted into non-agricultural areas. Due mainly to relatively higher economic rent, rapid expansion of industrial and service sectors in many Asian countries is mainly responsible for the misuse of agricultural land in the region.

Another obvious case of resource scarcity in Asian countries is declining water supply for agriculture. Water resource used to be abundant in the region which helps survive the majority of farmers in the rainfed areas. Trend is shown in many ways that rain, surface, and underground water for agriculture are all gradually declining. Moreover, increase in competitive use of water supply, especially from the surface water in rivers and reservoirs, has eventually put agriculture in the lower priority behind consumption, industrial, and tourism purposes. This is also indirectly influenced by effect of socio-economical improvement of population in other sectors of the economy.

Owing to such resource scarcity consideration, the continuity of agricultural sector into the future will depend in one way or another upon the development of technical innovation. Land-based agriculture will gradually be replaced by technology-based pattern of production especially in the areas of increasingly scarce resources. In general, technical innovation in agriculture is expected to substitute, complement, or supplement the natural resources whenever it is appropriate.

7. Conclusion

As long as many Asian countries still have to rely upon agriculture, the issue of technical innovation is always necessary to be discussed.

With all changes in economic development in each country or in international economy, agriculture is still expected to remain as an important part in Asian countries. Role of agriculture, however, may be declining in terms of export earning as compared with the contribution from non-agricultural sectors such as the industries and services. In terms of food and raw material production, residential sector, domestic employment, and social structure, agriculture still has to serve as the significant sector in Asian countries.

Successful development of Asian agriculture from subsistence to commercial farming has been much influenced by technical innovation. Traditionally, technical innovation aims to increase farm productivity at the same time reducing unit cost of production. For examples, mechanical innovation can act as the labor-saving technology while biological and chemical innovation will serve as the land-augmenting technology.

Along with the successful experience in Asian agriculture, technical innovation has also created many socio-economical effects to be evidenced. Negative effects on labor employment, net farm income, natural environment, and rural community structure are commonly found throughout the Asian countries together with the positive effect on leisure time and non-farm income. Taken into consideration all these external benefit and cost, the social eeeggeegvaluation is then suggested in stead of the technical evaluation when considering the technical innovation.

Despite the fact that technical innovation has produced significant socio-economical effects, rationale still exists for the need of technical innovation in the future. Not only considered as a consequence of technical innovation, changes in socio-economical conditions can also be considered the main cause of technical innovation for the Asian agriculture.

As one may see, the issue of technical innovation does not deal only with increasing farm productivity and reducing production cost. The issue can be investigated in relation to many external effects such as direct and indirect socio-economical conditions of a farm or the whole farm society. Accordingly, decision making upon technical innovation in agriculture should not be made solely by anyone but the whole team of interdisciplinary academicians. In other words, technical innovation is not a normal agricultural issue but rather it is an interdisciplinary matter.

Awareness in adopting technical innovation should be much more in case of the Asian agriculture which is relatively sensitive to any technological change. Even the Asian agriculture is now in search of the solution for its sustainability, technical innovation is not something possibly to take it for granted. Especially, while gap between agricultural and non-agricultural sectors still prevails significantly in this region of the world, innovation of agricultural technology must be performed with perfect knowledge. Some technologies considered suitable for one particular area or country may or may not be suitable for other areas or countries notably due to different socio-economical conditions. Successful technical innovation in agriculture therefore should not be evaluated only from measuring net farm profit but also from the social impact, change in welfare of farmers, as well as external cost to the rest of society where the agriculture belongs to as part of it.

References

1. FAO, Selected Indicators of Food and Agriculture Development in Asia-Pacific, 1981-91, Bangkok, 1992

2. George Honadle and Jerry VanSant, Implementation for Sustainability, Kumarian Press, Connecticut, 1985

3. Malcolm Gillis et al., Economic Development, W.W.Norton & Company, New York, 1987

4. Michael Todaro, Economic Development in the Third World, Longman Inc., New York, 1985.

5. Office of Agricultural Economics, Agricultural Statistics of Thailand, Ministry of Agriculture and Cooperatives, Bangkok, various issues.

6. Yujiro Hayami and Vernon Ruttan, Agricultural Development : An International Perspective, The Johns Hopkins University Press, Baltimore, 1985.

Recent Advances and Prospects in Weed Control Technology in Rice

H.Chisaka
The Japan Association for Advancement of Phyto-Regulators, Tokyo 110, Japan

Abstract. In rice cropping in Japan, weed control means "herbicide" in general, under the strong demands of farmers for labor-saving and complete weed control. Herbicide technology in transplanted rice has been developed by adopting the granular formulation and the mixture with two or more active ingredients. Sequential application of several herbicides has been replaced to one-shot application. In 1994, weeding hour was 20 hours/ha with 1.6 times of herbicide use on an average for the total rice field. Further improvements are making good progress, especially in new formulations. These are so-called "1 kg granule", "flowable" and "jumbo" formulation. In the near future, these new formulations will replace the conventional 3 kg granule and contribute much to efficiency of application practice. The environmental compatibility is requested more in weed control technology. As one of further tasks, it's very important to establish the technology which minimize run-off of herbicides from fields and economize herbicide use by forecasting incidence of weeds.

Progress of weed control by herbicides

There are various weeding methods in rice cropping. Herbicides among them, i.e. chemical weeding, are superior in weed control performance, handiness, economic efficacy and labor-saving to any other methods. Such superiority meets well rice farmers' demands for low-cost rice cropping with less-labor and eradicating weeds from their fields. Other methods, as mechanical or biological one, in spite of much effort in investigation, do not reach to the level of efficiency sufficient for practically wide use. So, weed control in rice heavily relies upon herbicides in present Japan.

Before 1950, when there was no herbicide available, weeds were removed by hands and/or man-power rotary cultivator which were repeated four or more times in one crop season, spending over 500 man-hours/ha. Manual weeding in hot and wet summer was strongly hard work for farmers.

2,4-D was introduced to practical use in 1949 and proved its value by significant herbicidal action and this success accelerated development and introduction of new herbicides so rapidly. Manual weeding was reduced year by year with the extention of herbicide use and the conventional herbicides were replaced by new, more effective ones. Then the total weeding hour including herbicide application practice has shrunken to 20 hours/ha in 1994. By the way, herbicide cost this year caluculates to labor-cost of 25 man-hours/ha, and combining these two figures gives 45 man-hours/ha equivalent for total weeding cost. This means less than 10 % of 1949 figures.

Herbicides for transplanted rice have advanced mainly by adopting the granular formulation and the mixture of two or more active ingredients. Rice herbicides of granular type generally show merits in the following points: handiness in application practice (possible to apply without any instruments), escaping from the injurious effects caused by direct contact to crops, and stable herbicidal activity by forming uniformly the active layer on soil surface.

Herbicide products containing two or more active ingredients aim to be effective for more broad weed spectrum. Besides this, in some products, synergistic action for weeds and antagonistic action to decrease the negative influence to rice growth are utilized and then enlarging selectivity between rice and weeds is expected.

Granules or mixtures was estimated to be used to more than 80 % or 75 % , respectively, of the total of herbicide treated acreage in 1994. Granules are applied to the field by hands, handy spreader or power spreader according to farming scale.

In recent years, about 30 products are available as major herbicides of rice, which are divided into several categories by their application time. These are soil-incorporating application after puddling, pre- or post-planting soil application, foliar and soil application, foliar application and one-shot application, as shown in Fig. 1. One or more herbicides among them are selected for use according to regional climate, rice cropping method, weed species to be controlled and other factors.

Before development of the one-shot herbicides, sequential treatment of herbicides of different categories was commonly practiced to achieve sufficient weeding. Especially, in such regions as cool climate where weeds tend to emerge longer period, three or more times of herbicide application was required. Aiming to minimize application times, improvement of products has advanced toward more broad weed spectrum of control achieved and more adequate persistence of activity in soil. Consequently, herbicides of one-shot application which possibly control weeds sufficiently by just one time of application practice were developed to practical use. One-shot application is extending for these ten years as shown in Fig. 2. and replacing gradually to the conventional sequential treatment, and then herbicide application times is steadily reducing from about 2.4 times in around 1980 to 1.6 times in 1994 on an average of the total rice fields (Fig. 3.).

Improvement of herbicide application techniques

The tendency to focus on herbicides as core technology of effective weed control is still going on. Above all, the easier application techniques which reduce labor intensity have been much sought in order to respond to aging of rice farmers and a large number of part-time farmers which are characteristics of rice cultivation in Japan. New formulations which meet such needs have been developed on the basis of advancement of formulation technology. These are so-called "1 kg granule", "flowable" and "jumbo" formulation.

"1 kg granule" (standard rate of application : 1 kg/0.1 ha) has been produced as a substitute of the conventional "3 kg granule"(3 kg /0.1 ha) by enhancing releasebility of active ingredients in water. As the percentage of active ingredients in "1 kg granule" is three times of it in "3 kg granule", "1 kg granule" products have shown equal or better herbicidal performance in comparison with "3 kg" ones, though number of granules/ha of "1 kg granule" are about one-tenth of that of "3 kg" ones.

"1 kg granule" can contribute to saving the natural materials required for granule formation and the logistics cost as well as to reducing the labor intensity for carriage and application practice. Most of granular products are expected to switch over to "1 kg granule" within these three or four years.

"Flowable" formulation has been produced as a stable suspension of active ingredients in a fluid with better diffusebility. The fluid of this products is able to apply directly into the paddy water from the holes of inner cap of bottle without any instruments. It can be applied not only by shaking bottle walking on levee of field, but also by pouring the fluid at water inlet of field at the time of irrigation. It is generally packaged in 500 ml bottle and its use rate is one or two bottles/0.1 ha. Several "flowable" products are increasingly used now practically.

"Jumbo" is the trade name of the throw-in type formulation of herbicides, and aims to get more handiness for application. Two types of formulation are investigated, one is bubbling tablet and the other is water soluble bag packaging granules. One tablet or bag is 50 g as standard, and 20 of them per 0.1 ha are thrown evenly onto the water irrigated field. Active ingredients diffuse rapidly in surface water and distribute uniformly over the field by the action of bubbling agent or other means.

As the result of much effort for improvement in diffusebility and for minimizing the local residue at the spot where tablets are placed, herbicidal activity of "jumbo" products has achieved to the satisfactory level.

Easiness of application is the major merit of "jumbo". It can be applied by hand from levee, even under somewhat bad weather, rainy or windy condition, without any drift, at the accurate application timing. At present, two "jumbo" products are already registered for use.

Herbicide use environmentally compatible

While herbicide use technology in rice has made a remarkable progress over the past forty years in its efficacy, technology progress has relieved safer herbicides with less toxicity to manmmal, fish or environmental organisms. The discovery and extension of low dosage herbicides in recent years resulted in decrease in the quantity of active ingredient per hectare. These have contributed to reducing environmental risks.

Increasing concern is neverthless being felt by many on account of wide use of herbicides, occasional undesirable side effects and environmental impacts. Certainly, it is very difficult to produce herbicide having no effect to any non-target organisms as environmental components. In spite of this, herbicides as core of weed control technology will continue to be needed and relied upon for the foreseeable future, owing to their economic efficacy. It is essential, therefore, to keep environmental impacts by herbicide usage within the range of buffering and recovering capacity of natural eco-system. Much efforts are still important for providing herbicides or herbicide usage with high environmental compatibility, suitable for application in integrated weed or pest control. At the same time, more attention should be paid to how minimize herbicide input to environment, considering the fact that knowledge concerning variation, diversity or buffering capacity of eco-system is not sufficient for evaluating the environmental impacts of new technology.

Paddy water connected directly to surface water system such as creek and pond, and herbicide run-off is top most concerned as a factor of environmental impacts. One of the practical ways for reducing herbicide run-off, besides preventing physically paddy water from leaking out, could be to economize herbicide use by forecasting the incidence of weeds. The amount and species of emerging weeds vary remarkably from field to field depending on the extent of weed control practiced previously. Extensive control of rice weeds during these decades has possiblly caused significant reduction in amount of certain species. If we could forecast the weed incidence as amount and species in each field before weeding practice, herbicide use with minimum but necessary amount of active ingredients could be selected for financial as well as environmental reasons. It's requested strongly to Weed Science to propose the practical, even empirical, technique of forecasting weed incidence on the basis of knowledge concerning weed ecology.

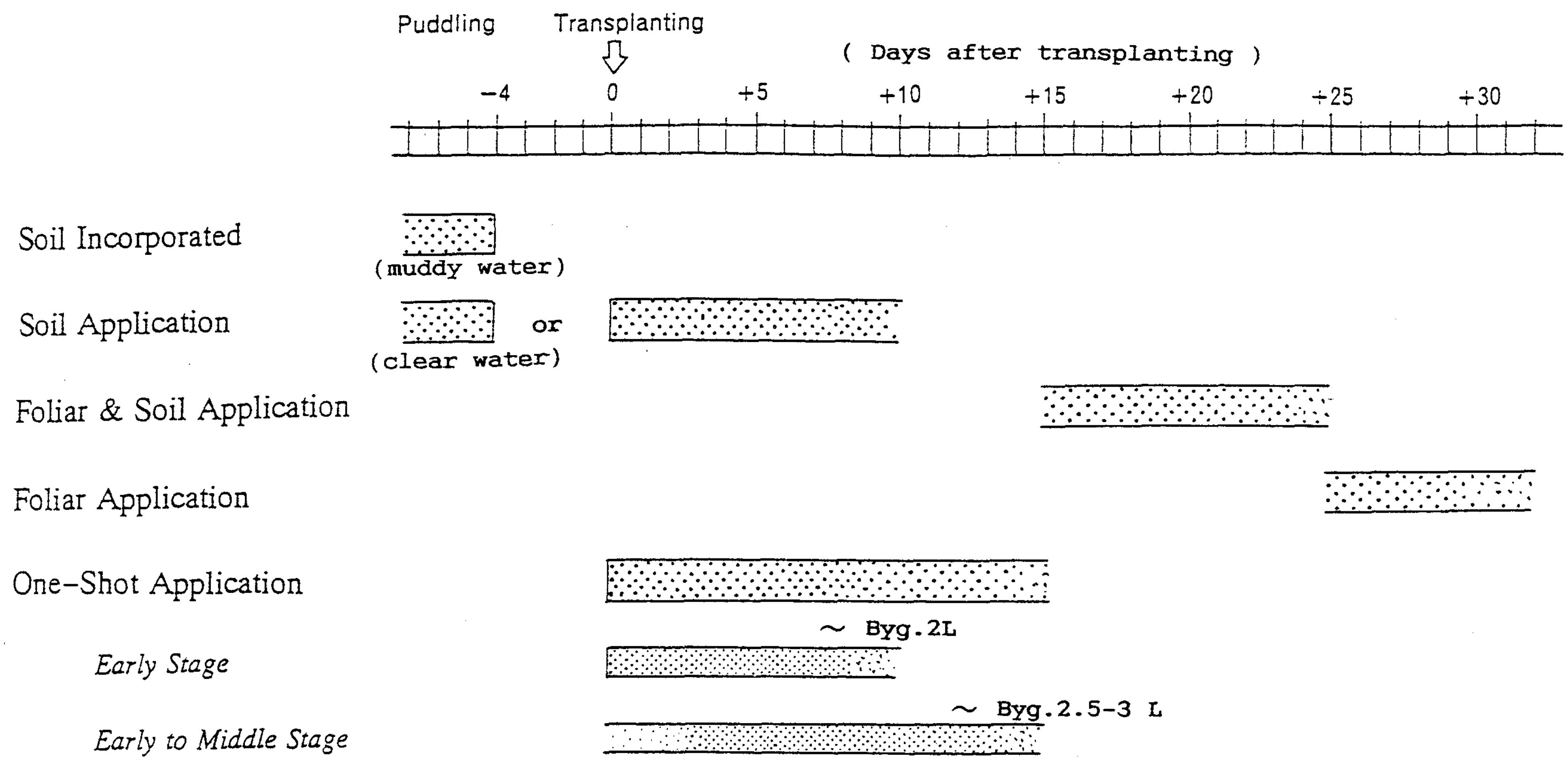


Fig. 1 Category of Herbicide Application Timming for rice

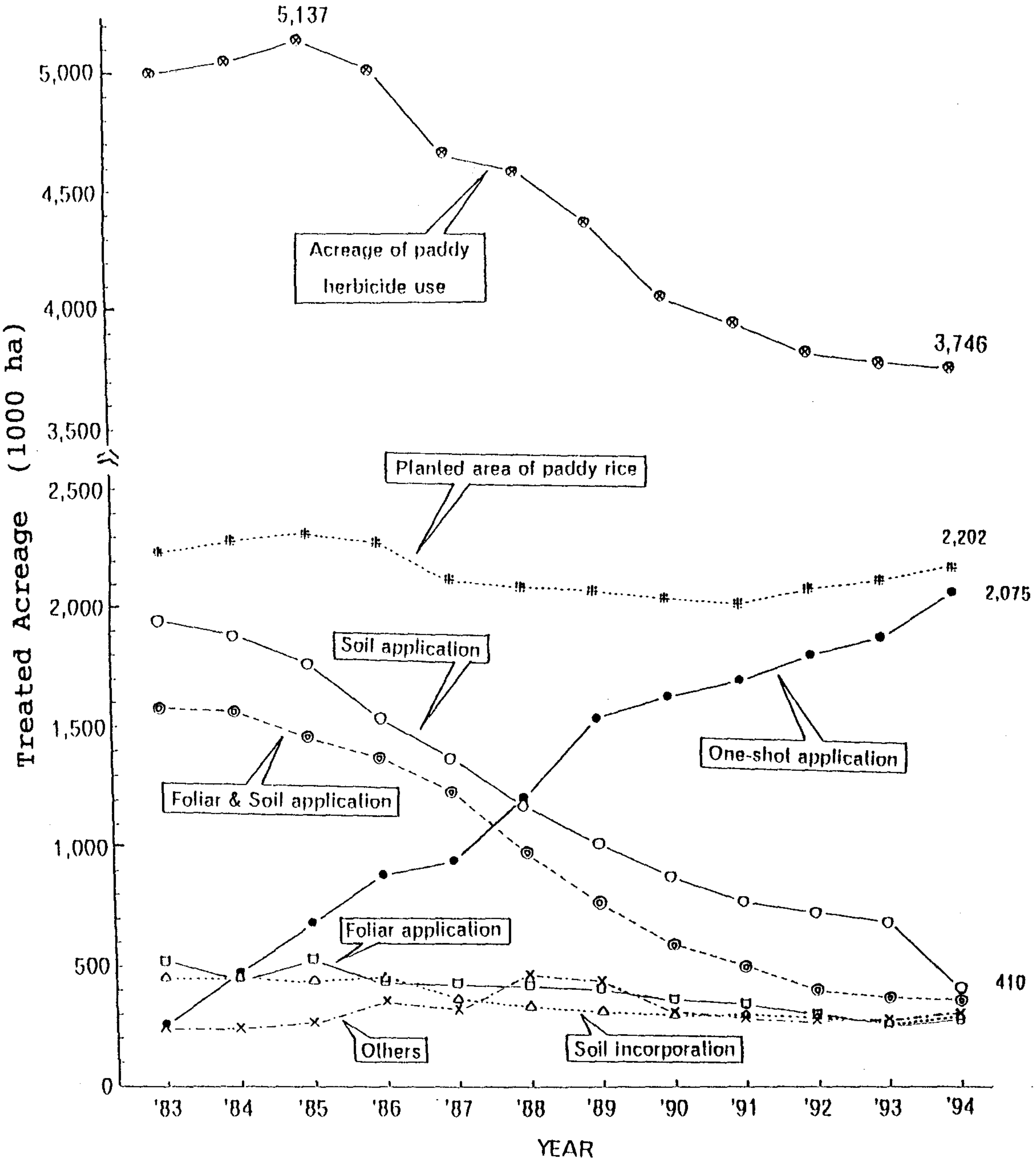


Fig. 2 Rice Herbicide Use in Japan

(From the statistics of MAFF and JAPR)

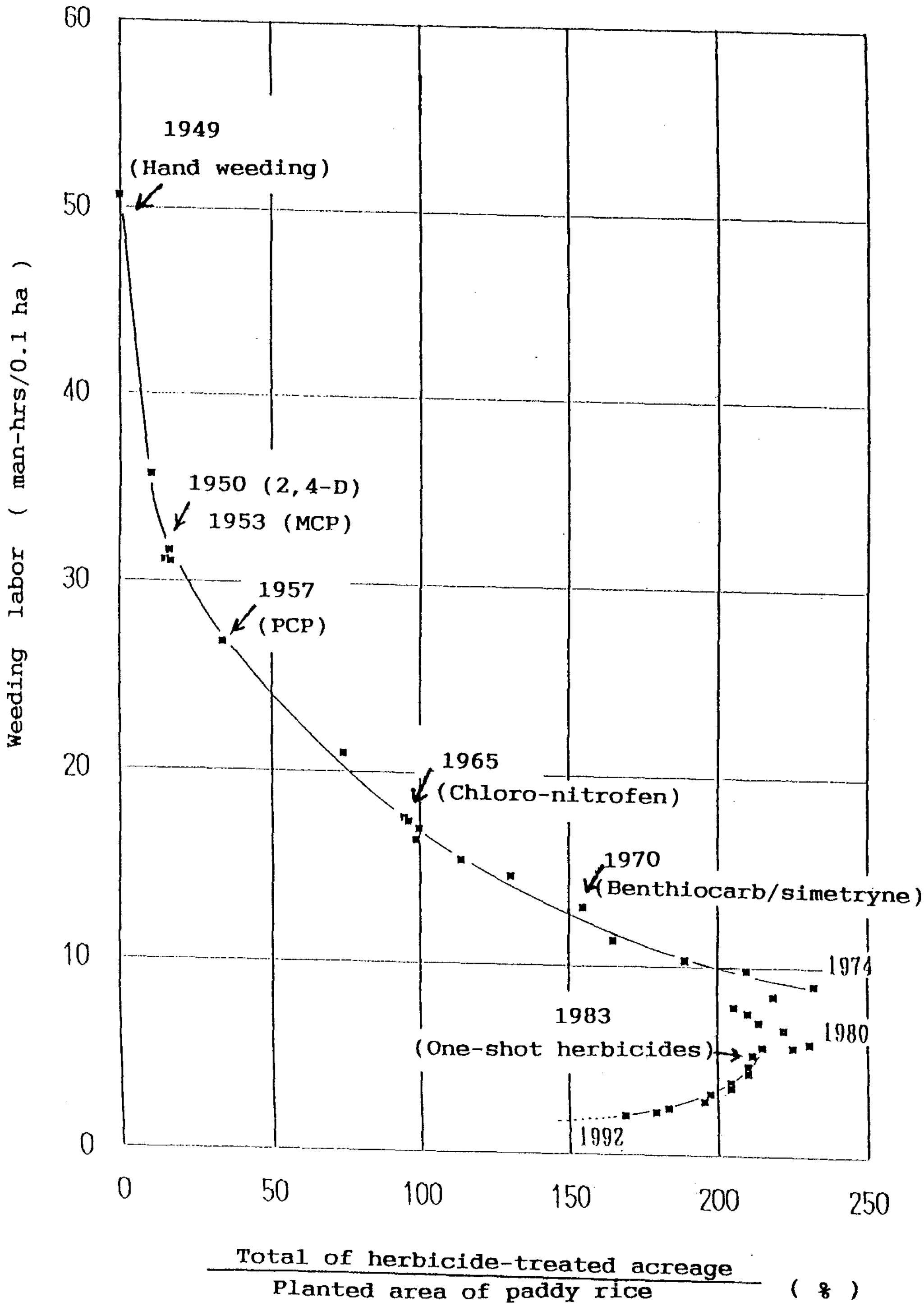


Fig. 3 Yearly Trends of Relationship between Weeding Labor and Herbicide-treated acreage in Rice

(From the statistics of MAFF and JAPR)

WEED MANAGEMENT PERSPECTIVES FOR SUSTAINABLE AGRICULTURE IN RICE-BASED SYSTEMS

S. K. De Datta
Professor, Crop and Soil Environmental Sciences, Director, Office of International Research and Development and Associate Dean, College of Agriculture and Life Sciences
Virginia Tech, 1060 Litton Reaves Hall, Blacksburg, Virginia 24061-0334 (USA)

Abstract. Demand for increased production of rice (Oryza sativa L.) and other food crops has caused intensive production systems to thrive, particularly on irrigated lands in Asia. This increase in cropping intensity and production of rice and other food crops has been sustained due to an increased use of fertilizers and pesticides. With that increase came misuse and overuse of herbicides, particularly in the direct-seeded rice areas. Even small land holders are using greater amounts of herbicides in order to decrease the cost of production of rice and other crops and increase farm income. Labor cost increase, unavailability of timely labor, and increased area under direct-seeded, flooded rice have contributed to such an increase in herbicide use in rice-based systems. Herbicides have a direct impact on fish, frogs, arthropods, and algae, and are thought to impact the producers in the food chain (algae, phytoplankton, etc.) that are considered important for the entire rice and estuary food production systems. However, many Asian farmers do not depend entirely on herbicides to control weeds. They use a weed management system that consists of direct removal or control of weeds by chemical and cultural methods. Systems approaches are essential for harnessing sustainability and environmental concerns. This will entail minimizing chemical approaches to systems, involving greater use of preventive, cultural, mechanical, biological, and integrated weed management systems. Researchers often have not recognized the economic impact of the integrated weed management concept, and few are concerned with the biological feasibility. This may have created the impression that all indirect and direct methods are pyramidal under one system. An applied, basic and strategic research including innovative techniques should be engaged in introducing germplasms and weed management technology that are consistent with and compatible to other productive practices in rice-based cropping systems.
Key Words. cropping systems, biological control, crop competitiveness, integrated weed management

I. Introduction

Asian rice (Oryza sativa L.) production has almost doubled since 1966 when the first modern variety IR8 was introduced. The average per capita rice consumption today is about 25% higher than it was in 1966. Unfortunately, the demand for rice will continue to increase because the rice-eating population will increase about 2% per year (Hossain and Laborte, 1993). As income rose in the rice-eating population in Asia, resources shifted from the production of rice to other food crops that have stronger markets. These scenario changes promote crop diversification, which discriminates against food grain production (David and Rosegrant, 1991). Recent interest has broadened from a single crop like rice research to systems research that seeks to increase benefits derived from total crop production and income from available resources. Whether rice is grown as a monoculture crop or as a component of cropping systems, annual crop losses due to weeds were estimated at 10% to 15% of potential production (Smith et al. 1977; De Datta, 1980). In most tropical Asian countries, year-round, moderately warm temperatures and high humidity encourage year-round weed growth. The kind and number of weed species associated with rice have been reported to be 1800 species in South and Southeast Asia, of which 559 were found in transplanted rice and 180 in broadcast-seeded flooded rice (Moody, 1989). However, only 10 species are considered to be of economic concern to the rice growers. The competitive advantage of weeds over rice is attributed to some weeds being C_4 plants, unlike rice, which is a C_3 plant; high photosynthetic rates and corresponding high growth rates; high potential to acclimatize to a changing environment; and more efficient seed production (Kim and Moody, 1989). In weed competition, studies reported critical thresholds or durations of competition and in others reported the nature of competition and its mechanism. Studies have determined herbicide behavior and factors affecting it. Studies on cost-effective control methods are limited to rice (Baltazar and De Datta, 1992). Few research projects have reported weed management in rice-based systems with holistic approaches that aim for maximum profit using integration of practices that maximize profits rather than maximize yields. Whether for rice or rice-based systems, environmental, ecological, human, and animal health concerns must be addressed simultaneously with other direct and indirect approaches in developing integrated weed management practices in rice-based systems. New and emerging knowledge and technology must be evaluated that will increase options for integrated weed management strategies and practices that will improve sustainability of the production systems.

My paper presents the various agronomic, ecological, and economic approaches that make up the integrated systems in managing weeds in irrigated rice and rice-based systems in Asia.

II. Weed Management in Rice-rice Systems

In irrigated rice production systems, rice is either grown transplanted or directly seeded. In tropical Asia broadcast seeding with pre-germinated rice is the most common method in directly seeded areas. Many reports are available on control methods of rice (Moody, 1991; Baltazar and De Datta, 1992). De Datta (1989) observed that many of these reports agree on several points:

1. There is a wide variety of control methods to match the wide diversity in weed species infesting rice.
2. No single method used in isolation can give effective and continuous control of all weeds in all situations.
3. The most effective methods are those that provide favorable stand establishment and growth for rice that are simultaneously unfavorable to weeds.
4. Best results are obtained when direct (therapeutic) methods are combined with indirect (prophylactic) methods and
5. The relative proportion of direct and indirect methods depends on the desired control level, available technology, growers1 resources and technical know-how, and probably most important, cost of control input in relation to net profit.

A. Direct cultural methods of weed control

There are a number of direct weed control methods used that were evolved because of socio-economic conditions.

1. Manual and Mechanical

Removing weeds with bare hands, weeding tools, or hand-pushed inter-row cultivators is the principal direct control method used in most parts of Asia, either alone or as a supplement to chemical control. In Japan, engine powered rotary weeders are used to control perennial weeds (which become dominant species once the annuals are controlled with selective herbicides) or in the fall or winter in between cropping seasons to expose underground propagules of perennials to freezing temperatures and kill them in the process (Shibayama, 1992).

2. Chemicals

In the past 20 years economic growth in rice producing areas in Asia created a relative shift of labor from agricultural to non-agricultural sectors, and has led to a rise in real labor costs in rural areas. As a result, many farmers are now substituting herbicides for manual labor as a method of weed control. The problem has been accentuated with the spread of broadcast- seeded, flooded rice technologies that are gradually replacing transplanted rice in many countries in Asia (Naylor, 1994).

Woodburn (1990) estimates that the total value of herbicide sales for rice production in Asia is about U.S. $700 million with larger sales occurring in Japan, Korea, and Taiwan. Other less developed rice-growing countries in Asia have increased their share of herbicide sales during the past decade. Naylor (1994) contends that with continued economic expansion in these countries, the use of herbicides is expected to grow further. Herbicide use is directly corresponded to the real wages in rice production. For example, during the 1970s and 1980s in Bangladesh, where real wages are low and in fact declined, herbicides were not used at all. Herbicides are applied in virtually all the rice-producing areas in Japan and Korea, where real wages -- already at high levels -- rose at an annual rate of 2.1 percent and 6.7 percent, respectively (Naylor, 1994).

In the 1960s and 1970s, pre-emergence herbicides such as butachlor, thiobencarb, pendimethalin, molinate, propanil, and other pre- and post- emergence compounds, were used primarily to control grass and some broadleaf and sedge control. The late 1970s saw the advent of bentazon for post-emergence control of broadleaf weeds and sedges. The 1980s saw the new post-emergence compounds with very low use rates, which were first primarily intended for broadleaf crops, but eventually shown to have adequate selectivity for rice. These compounds included fluazifop, diclofop, fenoxaprop, bensulfuron and quinchlorac (Baltazar and De Datta, 1992). The most effective time of application is from germination to no later than one-leaf stage of weeds for pre-emergence treatments, and from one-leaf to no later than four-leaf stage of weeds for post-emergence treatments. Phenoxys, amides, and carbamates are widely used in Thailand, Malaysia, Taiwan, Indonesia, and the Philippines, while the new compounds (sulfonylureas) and their mixtures are now widely used in Korea and Japan. Table 1 shows some examples of commonly used rice herbicide mixtures in selected countries in Asia.

Currently used rice herbicides generally have adequate selectivity to rice. However, because rice is also most susceptible to herbicide treatments at the same growth stages as weeds (ie. from germination to four-leaf stage), certain selectivity problems may occur with grass herbicides, which do not have adequate physiological selectivity to rice (De Datta and Baltazar, 1994). Marginal selectivity and rice injury greater than 30% can occur with grass herbicides applied when moisture levels are excessive, e.g., if heavy rainfall occurs just before or after herbicide application (Bernasor and De Datta, 1983). Flooded and wet-seeded rice usually incur greater injury than dry-seeded or upland rice (Baltazar et al., 1990) suggesting the critical role of moisture on herbicide selectivity, particularly with grass herbicides. Flooding a field for a month after pre-emergence herbicide application can provide adequate weed control in lowland rice (De Datta, 1981). A recent study (Pablico and Moody, 1993) reported flooding duration had no effect on pretilachlor performance at an application rate of 0.15-0.30 Kg a.i./ha. The herbicide rate could be reduced to 50% of that recommended rate without loss in efficiency across all flooding regimes. It appears that fenoxaprop was completely selective to nonflooded rice when tested in the greenhouse. In the field, fenoxaprop exhibited slight to moderate toxicity to transplanted and wetseeded rice at initial growth stages but recovered fully by mid-season (Baltazar, et al., 1993).

3. Biological

The biological control of weeds is the deliberate use of natural enemies to suppress the growth or reduce the population of a problem weed species (Watson, 1993). Only a few studies have reported evaluations of biological methods of weed control in rice. However, interest is growing in systems of biological control that reduce the use of herbicides in order to avoid environmental pollution and protect human, animal, and aquatic health. Biological agents to control rice weeds are herbivores, insects, plant pathogens, and allelochemicals.

3a. Herbivores

Herbivores to control certain rice weeds are used in small scale in some areas in Asia or are being studied for potential widespread use. In Japan, for example, the use of tadpole shrimp has been reported to have some success (Matsunaka, 1975). Some snails

(Lymnaea sp. and Physa sp.) have also been reported to control some rice weeds in Japan (Gohbara and Yamaguchi, 1993). Other studies reported were the use of grass carp in Indonesia (Soewardi, et. al., 1977), Malaysia and Japan (Itoh, 1991), shellfish and ducks in Japan (Takahashi, 1992; Shibayama, 1992) and in the U.S. (Smith and Sullivan, 1980), and apple snail in Taiwan (Chiang, 1993). Helmet crab (Triopus longicaudatus) has been used as an herbivore in Japan for 80 years (Gohbara and Yamaguchi, 1993).

3b. Insects

One biological strategy for weed control in rice includes insects. In California, water lily aphids controlled some aquatic weeds selectively in rice (Smith, 1993). Because carbaryl, and perhaps other insecticides, kill water lily aphids, this control strategy would have to be integrated with other insect control programs using the IPM concept to prevent damage to the aphid.

Catindig et al. (1991) reported that three insects, i.e. (Creatonotus gangis L., Mythimna separata (Walker), and Pseudococcus saccharicola showed biocontrol potential against rice weeds. They caused extensive defoliation, destruction, and hopperburn of unwanted weeds, respectively, in the Philippines. For various reasons,Waterhouse (1993) suggests that out of 61 species listed as major weeds in rice, only six are likely targets for classical (use of insects or natural enemies): Monochoria vaginalis, Fimbristylis miliacea, Ehinochloa crusgalli, Ageratum conyzoides, Sphenoclea zealanica, and Rottboellia cochichinensis.

3c. Plant Pathogens

Several pathogens have been identified to have the potential of controlling important rice weeds. A successful biocontrol study was conducted in the U.S. when the endemic fungus Colletotrichum gloeoesporioides (Penz.) Sacc. f. sp. aeschynomene was discovered in 1969

(Daniel et al., 1973; Templeton et al., 1980) to cause anthracnose in a broadleaf weed that infects rice, northern jointvetch (Aeschynomene virginica L.) . Its efficacy has been used as a biocontrol agent for 13 years, which led to commercial use in 1982 (Smith, 1986). It is highly specific only against this weed and provides 90 to 100% control. Colletotrichum truncatum has controlled sesbania in rice in the United States (Smith, 1993). In Japan various species of fungi belonging to the genera Fusarium, Rhizoctonia, Phoma, Drechslera, etc. were found to have naturally infected barnyard grass (Gohbara and Yamaguchi, 1993). Watson (1993) surmised that the prospect for the development and utilization of bioherbicide technology for major rice weeds is good. Virulent pathogens of some potential weed targets have been identified. Mutation, recombination, and direct gene transfer are methodologies available to genetically modified fungi.

To date, there is no known successful widespread use of inundative (use of plant pathogen inoculum or mycoherbiciedes) biological control methods to control weeds in rice in Asia. However, Kim (1992) reported a pathogenic fungi Alternaria sp. that was reported to control Scirpus panicalmis, which is a potential perennial stage in the newly reclaimed land on the west coast of Korea.

3d. Allelochemicals

Potentials of allelopathy for weed control has been reviewed by Purvis (1990) and Watson (1992). Identification of rice cultivars having allelopathic activity against certain weeds has been done in the U.S. (Smith, 1992) and in Japan (Fujii, 1992), but there is no real widespread use of this method yet. Crop residues from barley, wheat, and rye have allelopathic compounds such as ferulic acid, p-coumaric, sinapic, etc., which have allelopathic potential to reduce the population of Potamogeton distinctus, a major rice weed in Korea. Further studies are needed to identify specific allelochemicals (Kim, 1993). Future research programs involving development of allelochemicals should consider availability of facilities needed to produce these chemicals locally, should this technology be considered for the developing Asia.

B. Prevention and Substitutive Cultural Methods of Weed Control

Weed control practices that had been widely studied include the indirect (preventive, substitutive, and complementary).

1. Tillage

Land preparation, especially puddling and harrowing, provides weed-free conditions at planting, aids in good crop establishment, and often minimizes weed growth in the established crop. Increased frequency of harrowing will not eliminate the need for a direct measure. Farmers still have to follow land preparation with direct weed control methods.

2. Rice Cultivar

Replacing tall, traditional rice cultivars with modern rice has often been equated with the loss of competitiveness of rice against weeds. But tall and late-maturing cultivars are not always superior in suppressing weed growth.

3. Planting Density

Close spacing is essential to minimize weed infestation and increase grain yield. Many farmers use high seeding rates to control weeds in broadcast-seeded flooded rice. But the increase in cost due to increased seeding rates should be compared with that of lower seed rates combined with other weed control practices, to assess profitablility.

4. Water Management

The weed suppressing ability of standing water has long been recognized. Weed emergence and weed types are greatly influenced by soil moisture and water depth in the rice field. Growth of broadleaf aquatic weeds (i.e. Monochoria vaginalis) is suppressed at saturation or field capacity while growth of low moisture-requiring grasses (i.e. Echinochloa crusgalli) is suppressed at greater water depth (e.g., 2.5 cm. or more) (Moody, 1991). Adequate moisture is, however, needed for optimum herbicide efficacy.

5. Crop Rotation

Rotating flooded rice with an upland crop to dry out and kill moisture-loving weeds is an effective weed control method. Scirpus maritimus populations were observed to increase with continuous cropping of irrigated, transplanted rice, but were decreased in density when irrigated, transplanted rice was rotated with an upland crop (Bernasor and De Datta, 1986). In Korea and Japan, choice of rotation crops with rice depends on potential market value of the crop (Kim, 1992). Because some herbicides cannot be used with certain crops for reasons of selectivity, rotation of crops will mean rotation of herbicides, thus preventing continuous use of same herbicide and subsequent build up of weed tolerance (De Datta and Baltazar, 1994).

III. Weed Management in Rice-Based Cropping Systems

The rapid income growth in China, Thailand, and Indonesia will reduce per capita consumption of rice. The growth in demand for rice has started slackening due to rapid urbanization, higher incomes, and decreased population growth (Hossain and Laborte, 1993). As a result of reduced demand for rice, research on cropping systems involving upland crops in rotation with lowland rice has been intensified throughout Asia. Such cropping systems research seeks benefits derived from crop production from available resources through intensified cropping patterns. In many advanced countries, public attitude has shifted from environmental awareness to environmental action. Many of these concerns have focused on environmental, economic, and social impacts of conventional agriculture. Of the 23 countries in the world that produce more than one million tons of rice, almost half have a per capita income of less than U.S.$500 per year. These countries are the least developed, as categorized by the World Bank (Hossain and Laborte, 1993). Therefore, considerable interest has developed to introduce high value crops in rice-based systems to increase income and improve nutrition. Cropping systems can be used to minimize crop damage from weeds. Crop rotations recognize that certain weeds are often associated with specific crops. Moody (1990) pointed out that relations among crops with drastically dissimilar life cycles or cultural conditions are preferred to break the weed cycle. This is one of the most effective of all weed control methods.

Rotation of lowland rice with an upland crop will reduce infestations of water-tolerant weeds in rice fields. Upland crops commonly rotated with rice are maize, soybean, mungbean, peanut, wheat, barley, and pastures. Over large areas of North India, irrigated wheat is grown in the cool season, followed by rice in the monsoon season.

In China there is no area that grows rice continuously. One or two crops of rice are grown with other upland crops, including other cereals, legumes, and vegetables.

A. Non-Chemical Approaches and Practices

1. Cultural weed control covers a wide range of practices such as physical removal by hand implements or machines, competition from crops or pasture grown either in sequence or in association with main crops, use of dead vegetative materials such as mulch, and other biological control methods using predators or pathogens (Wells, 1992).

In irrigated lowlands, short duration legumes such as soybean or peanut are often grown after lowland rice. Very little is known on the ecology of weeds in these crops. However, the simplest method of weed control in soybean fields is to spread rice straw over the soil surface of the lowland field and then burn it. The field is then irrigated and soybean seeds are drilled into soil with planting sticks. If the burn is complete, the weed growth is minimal and weeds are covered by a soybean canopy (Wells, 1992).

On the other hand, peanut crop is grown on raised beds and weeds are removed by hand or removed by small implements. In many areas in South and Southeast Asia, soil moisture is extremely limited in the dry season. Unless supplementary irrigation water is available, very few crops can be grown. One possible exception has been growing deep rooted lab Lab bean (Lablab purpureus or pigeonpea (Cejanus cajan).

2. Weed Ecology

Knowledge about crop-crop and crop-weed interactions can be best utilized to develop appropriate systems approaches to cropping systems involving lowland rice and upland crops following the steps described below:

(i) Study factors affecting crop-weed competiton
(ii) Develop a model utilizing cultural, manual, mechanical, chemical, and biological methods or combinations of these to create an environment that is detrimental to weeds and favorable to crops
(iii) Study the dynamics of weed community and monitor weed shifts
(iv) Explore the possibility of shifting the weed flora toward more easily controlled species.
(v) Study the life cycle of "difficult to control" weeds to "know the enemy" (Plucknett, et al., 1977).

3. Weed Shift

For the last two decades, there has been an increased recognition regarding "weed shifts" toward perennials and difficult-to-manage weeds (De Datta, 1974; Cao and Mercado, 1975).

Perennials that pose problems in lowland rice in the tropics are Scirpus maritimus and other Sciripus spp. When lowland rice was rotated with upland crops such as maize or soybean, perennials such as Scirpus maritimus weeds were not able to build up (De Datta and Jereza, 1976).

Yield depressions due to weeds in lowland rice in this rotation were lower than under continuous lowland conditions. Cyperus rotundus occurs only under upland conditions. Moody and De Datta (1982) also reported that annual weeds caused complete crop failures for continuous lowland rice and continuous upland crops. In Punjab, India Gill and Brar (1972) observed Phalaris minor, a relatively minor weed when wheat is grown alone, is increasing at alarming rates in an intensive rice - wheat crop production systems. Yamasue and Ueki (1981) reported that lowland weeds have a lower oxygen requirement for germination than upland weeds. As a result, rotation of a lowland rice with an upland crop such as corn, mungbean, sweet potatoes, vegetable crops, or pastures will result in reduced infestations of water-tolerant weeds in the rice crop (Moody, 1983b).

B. Chemicals

Throughout Southeast Asia, particularly the Philippines and Indonesia, chemical weed control has made a major penetration into annual cropping systems.

In areas of intensive cropping systems involving rice and vegetables, chemicals in combination with rotary hoes are used to control weeds (Norman, 1979). In intensively managed production systems, the diversity of weed species has been reduced due to application of highly sophisticated control techniques. For example, herbicide use reduces diversity. Residues of herbicides applied to rice are rarely a problem in succeeding upland crops (Moody, 1983b).

IV. Integration of Approaches and Practices for Weed Management

Various approaches should be considered to develop an integrated weed management (IWM) system that takes all aspects of the cropping systems into consideration.

Among the factors that must be considered in developing IWM are as follows:

A. <u>Conventional tillage</u>, which advocates the maintenance of crop residue cover on 30% of the soil surface. Swanton and Weise (1991) advocate that the potential for a reduction in herbicide use is greater in conservation tillage, particularly in no-till, than can be achieved in conventional tillage systems. However, this approach should be carefully evaluated in the lowland rice-based cropping systems.

B. <u>Critical period of weed growth</u>

Two components are considered:

1. the length of time weed control methods must be maintained to prevent crop yield loss
2. the length of time weeds can remain in the crop before they interfere with crop growth and ultimately reduce yield

C. <u>Enhancement of Crop Competitiveness</u>

Cultivar competitiveness, planting patterns, and nutrient management are some of the approaches that attempt to effectively exploit the competitive ability of crops in suppressing the weed growth.

V. IWM as a Component of Integrated Pest Management (IPM)

Most descriptions of IPM mention three elements:

a. multiple tactics (for example, competitive varieties, cultural practices, chemical usage) used in compatible manner
b. pest populations maintained below levels that cause economic damage
c. conservation of environmental quality (Thill et al., 1991)

The term IPM was first introduced by entomologists in late 1950s and early 1960s in response to problems created by over-reliance on insecticides. According to Walker and Buchanan (1982), Integrated Weed Management (IWM) is a term that has been accepted and that was used frequently by weed scientists in the early 1970s. IWM stresses integration of control tactics with other practices that influence the ecosystem, and links weed control back to the larger picture of ecosystem management (Thill, et al., 1991).

The general principles for IWM are similar to IPM. The principles are enhancing farmer profitability, environmental stewardship, and responsiveness to consumer calls for pesticide-safe foods.

VI. Sustainable Systems

Natural resource management is key to sustainable agricultural production. It plays a role, for example, in Asia's high intensity production systems. Where yields are now stagnating and even declining, agriculture and agricultural research therefore lies at the heart of natural resources management. Further productivity in rice-based systems will depend not only on new technology, but also on institutional reform, policy changes, and ecosystem management.

The trend of use pattern for weed control has changed from mainly handweeding in the 1950s and 1960s when labor was cheap, to increased use of herbicides from the 1970s to the present, when herbicide prices are lower than or equal to labor cost.

Naylor (1994) suggests that herbicide use may be socially profitable in a wide range of Asian countries, but complete and continuous chemical weed control may not be the most socially profitable practice, especially when the unknown chronic health and long-term environmental changes are considered. There is a cost to a disaggregated knowledge-based approach, which must be considered in the overall assessment of implementing IWM strategy. The process of training farmers, extension agents, and others is slow and expensive (Teng, 1989). A successful IWM strategy is therefore likely to depend critically on the coordinated efforts between public and private sectors on appropriate use of herbicides and other control measures in the rice-based cropping systems. Increased information needs, complex policy decisions, and interdisciplinary research needs all have important implications for natural resource management.

Therefore, it is imperative that new weed science research agenda be pursued using cutting edge of science and new tasks be assumed that will lead to sustainable rice-based production systems in Asia.

VII. References

1. Baltazar, A. M. and S. K. De Datta. 1992. Weed management in rice. Weed Abstracts. CA.B. International 41 (11): 495-508.
2. Baltazar, A. M., S. K. De Datta, and M. A. Llagas. 1993. Efficacy and selectivity of Fenoxaprop for postemergence grass control in rice (Oryza rativa L.). Philippine J. Weed Sci. 20: 45-55.
3. Baltazar, A. M., S. K. De Datta, T. R. Migo, M. A. Llagas, and J. V. Bariuan. 1990. Efficacy and selectivity of fenoxaprop for postemergence control of weeds in rice. Proc. Southern Weed Sci. Conf. U.S.A. pp.63-120.
4. Bernasor, P. C. and S. K. De Datta. 1983. Integration of cultural management and chemical control of weeds in broadcast-seeded flooded rice. Proc. 9th, APWSS. Manila, Philippines. pp.137-155.
5. Bernasor, P. C. and S. K. De Datta. 1986. Chemical and cultural control of bulrush (Scirpus maritimus L.) and annual weeds in lowland rice (Oryza sativa L.) Weed Res. 26: 233-244.
6. Cao, N. D. and B. L. Mercado. 1975. Growth behavior of scirpus maritinus. Proc. 5th APWSS. Tokyo, Japan. pp. 50-53.
7. Catindig, J. L. A., A. T. Barrion and J. A. Litsinger. 1991. Potential weed hosts of fourteen rice insect pests in rainfed wetland and irriganted lowland rice environments in the Philippines. Paper presented at the 22nd PMCP Conference May 8-10, 1991. Manila, Philippines. (unpub. memeo.).
8. Chiang, M. Y. 1993. Integrated management of paddy weeds in Taiwan. FFTC, Taiwan, R.O.C. Extn. Bull. No. 368. 8 p.
9. Daniel, J. J., G. E. Templeton, R. J. Smith, Jr. and W. T. Fox. 1973. Biological Control of northern jointvetch in rice with an endemic fungal disease. Weed Science 21: 303-307.
10. David, C. C. and M. W. Rosegrant. 1991. Asian rice economy: Issues and agenda for research. Prospects for the research project on projections and policy implications of medium- and long-term rice supply and demand. IRRI and IFPRI. Unpub memeo.
11. De Datta, S. K. 1974. Weed control in rice: Present status and future challenge. Philipp. Weed Sci. Bull. 1(1): 1-16.

12. De Datta, S. K. 1980. Weed Control in rice in South and Southeast Asia. FFTC. Taiwan, R.O.C. Extn. Bull. No. 156. 24 p.
13. De Datta, S. K. 1981. Principles and Practices of rice production. John Wiley and Sons. New York. 681 p.
14. De Datta, S. K. 1989. Technology and economics of weed control in small rice farms in the Asian tropics. Proc. APWSS Conference. 1989. pp.23-37.
15. De Datta, S. K., and A. M. Baltazar. 1994. Agronomic and Ecological Approaches to Integrated Weed Management in Rice in Asia. Paper presented at a conference on ≯Herbicide Use in Asian Rice Production ‡ March 28-30, 1994. Stanford U. Stanford, CA. USA. (in press).
16. De Datta, S. K. and A. M. Baltazar. 1995. Weed Control Technology as a component of rice production systems. FAO, Rome (in press).
17. De Datta, S. K. and J. C. Jereza. 1976. The use of cropping systems and land and water management to shift weed species. Philipp. J. Crop Sci. 1: 173-178.
18. Fujii, Y. 1992. The potential biological control of paddy weeds with allelopathy: allelopathic effects of some rice varieties. Proc. International Symposium on Biological Control and Integrated Management of Paddy and Aquatic Weeds in Asia. Tsukuba, Japan. 305-320.
19. Gill, H. S. and L. S. Brar. 1972. Investigations on the chemical control of Phalaris minor L. in wheat. Punjab Agric. Univ. Res. J. 9: 287-294.
20. Gohbara, M. and K. Yamaguchi. 1993. Biological agents for the control of paddy weeds in Japan. FFTC. Taiwan, R.O.C. Extn Bull. No. 369. 11 p.
21. Hossain, M. and A. Laborte. 1993. Asian rice economy: Recent papers and emerging trends. FFTC. Taiwan, R.O.C. Extn. Bull. No. 378. 20 p.
22. Itoh K. 1991. Life cycles of rice field weeds and their management in Malaysia. Tropical Agric. Res. Center. Japan. 89 p.
23. Kim, K. U. 1992. Current status of biological control and integrated management of paddy weeds in Korea, with emphasis on allelopathy of weeds. Proc. International Symposium on Biological Control and Integrated Management of Paddy and Aquatic Weeds in Asia. Tsukuba, Japan. 285-303.
24. Kim, K. U. 1993. Integrated management of paddy weeds in Korea, with emphasis on allelopathy. FFTC. Taiwan, R.O.C. Tech. Bull. No. 134. 23 p.
25. Kim, S. C. and K. Moody. 1989. Growth dynamics of rice and several weed species under density and fertilizer stresses. Proc. APWSS Conf. 1989. pp. 47-56.
26. Moody, K. 1983a. Ecological factors affecting weed population shifts. In: Weed Management in the Philippines. PLITS 1(1). H. Walker (Ed.). Institut fur Planzen produktion in den Tropen and subtropen, Universitat Hohenheim, Stuttgart, FR Germany, pp. 133-151.
27. Moody, K. 1983b. Weeds in rice-based cropping systems. Proc. symposium on weed control in cropping systems, 9th APWSS Conference, Manila, Philippines. pp 1-22.
28. Moody, K. 1989. Weeds reported in rice in South and Southeast Asia. IRRI. Philippines. 442 p.
29. Moody, K. 1990. Weeds and their control in rice and rice-based cropping systems. Proc. of the 1987 International Congress on Plant Protection. pp. 32-37.
30. Moody, K. 1991. Weed management in rice. In: Handbook of Pest Management in Agriculture, 2nd ed. (Ed. by Pimentel, D.). pp. 301-328. CRC. Press, Inc., Florida, USA.
31. Moody, K. and S. K. De Datta. 1982. Integration of weed control practices for rice in tropical Asia. In M. Soerani, D. E. Barnes, and T. O. Robson (eds.). Weed control in small farms. APWSS. BIOTROP Spec. Publ. No. 15, Bogor, Indonesia. pp. 37-47.
32. Naylor, R. 1994. Herbicide use in Asian Rice production. World Development 22 (1): 55-70.
33. Norman, M. J. T. 1979. Farming Systems of Southeast Asia. Proc. 75th APWSS Conf. Sydney, Australia. pp. 1-6.
34. Pablico, P. P. and K. Moody. 1993. Effect of flooding duration on the performance of pretilachlor and fenclorim in wet-seeded and transplanted rice. Philippine J. Weed Sci. 20: 56-61.
35. Plucknett, D. L., E. S. Rice, L. C. Burrill, and H. H. Fisher. 1977. Approaches to weed control in

cropping systems. Proc. of the Symp. on Cropping Systems Research and Development for the Asian Rice Farmers IRRI. Philippines. pp. 295-308.
36. Purvis, C. E. 1990. Allelopathy: a new direction in weed control. Plant Protection Quarterly 5: 55-59.
37. Shibayama, H. 1992. Integrated management of paddy weeds in Japan: current status and prospect for improvement. Porc. Int. Symp. on biological control and integrated management of paddy and aquatic weeds in Asia. Tsukuba, Japan. 1992. pp. 161-177.
38. Smith, R. J., Jr. 1986. Biological control of northern jointvetch (Aechynomene virginica) in rice (Oryza sativa) and soybeans (Glycine max) -- a researcher□s view. Weed Science 34: 17-23 (supplement 1).
39. Smith, R. J., Jr. 1992. Biological Controls as components of integrated weed management for rice in the United States. Proc. International Symposium on Biological Control and Integrated Management of Paddy and aquatic weeds in Asia. Tsukuba, Japan. 335-351.
40. Smith, R. J., Jr. 1993. Biological Controls as Components of integrated weed management for rice in the United States. FFTC. Taiwan, R.O.C. Extn. Bull. No. 376. 9 p.
41. Smith, R. J., Jr and J. D. Sullivan. 1980. reduction of red rice grain in rice fields by winter feeding of ducks. Arkansas Farm Res. 29 (4): 3.
42. Smith, R. J., Jr, W. T. Flinchum, and D. E. Seaman. 1977. Weed Control in rice production. Agri. Handbook No. 497. U.S.D.A. Washington, D.C. 78 p.
43. Soewardi, K, M. L Nurdjana, and I. J. B. Lelana. 1977. Some ecological impacts of the introduction of grasscarp (Ctnophyryngodon idella val.) for aquatic weed control. APWSS 1977, pp 451-458.
44. Swanton, C. J. and S. F. Weise. 1991. Integrated Weed Management: The rationale and approach. Weed Technology 5: 657-663.
45. Takahashi, F. 1992. The tadpole shrimp (Triops spp.) for biological control agents of paddy weeds in Japan. Proc. International Symp. on Biological Control and Integrated Management of Paddy and Aquatic Weeds in Asia. Tsukuba, Japan. pp. 259-272.
46. Templeton, G. E., R. J. Smith, Jr., and W. Klomparens. 1980. Commericialization of fungi and bacteria for biological control. Biocontrol News and Information 1: 291-294.
47. Teng, P. S. 1989. Integrated Pest Management in Rice: An analysis of the status quo with recommendations for action; A report prepared for the ACIAR/IDRC/FAO/ONNRI/USAID Task Force on IPM. IRRI, Philippines. 1989.
48. Thill, D. C., J. M. Lish, R. H. Callihan, and E. J. Bechiniski. 1991. Integrated Weed Management -- A Component of Integrated Pest Management: A Critical Review. Weed Technology. 5: 648-656.
49. Walker, R. H. and G. A. Buchanan. 1982. Crop manipulation in integrated weed management systems. Weed Sci. (suppl.) 30: 17-24.
50. Waterhouse, D. F., 1993. Prospects for biological control of paddy weeds in Southeast Asia and some recent successes in the biological control of aquatic wees. FFTC. Taiwan, R.O.C. Extn. Bull. No. 366. 10 p.
51. Watson, A. K. 1992. Biological and other alternative control measures. Proc. First International Weed Control Congress. Melbourne, Australia. 1: 64-73
52. Watson, A. K. 1993. Current status of bioherbicide development and prospects for rice in Asia. FFTC. Taiwan, R.O.C. Extn. Bull. No. 365. 7 p.
53. Wells, G. J. 1992. Non-chemical weed control in tropical crops of developing countries. Proc. 1st International Weed Control Congress, Melbourne, Australia. 1992. pp. 295-301.
54. Woodburn, A. 1990. The current rice agro-chemical market. In: B.T. Grayson, M. B. Greene, and L. G. Cropping (eds.). Pest Management in rice. London and New York: Elsevier Applied Science.
55. Yamasue, Y. and K. Ueki. 1981. Biology of paddy weeds and their control in lowland rice. Paper presented at the IRRI/IWSSS Conference on Weed Control in Rice, Aug. 31-Sept. 4, 1981. IRRI, Philippines.

Table 1. Examples of commonly used rice herbicide mixtures in selected countries in Asia. (Adapted from De Datta and Baltazar, 1994).

Country	Herbicide mixture
Malaysia	pretilachlor + bensulfuron-methyl
	molinate + bensulfuron-methyl
	quinclorac + bensulfuron-methyl
Japan	mefenacet + bensulfuron-methyl[1]
	mefenacet + thiobencarb + bensulfuron-methyl
	molinate + simetryn + MCPB
	mefenacet + pyrazosulfuron + ethyl
	butachlor + pyrazolate
Taiwan	butachlor + chlomethoxynil
	butachlor + bensulfuron-methyl
	butachlor + oxadiazon
Thailand	propanil + 2, 4-D
	butachlor + 2, 4-D
	propanil + thiobencarb
	propanil + molinate

[1]All combinations listed for Japan are one-shop treatments, applied either preemergence or early postemergence.

Current Scenario and Future Lines of Weed Management in Rice Crop with Particular Reference to India

Sisir K. Mukhopadhyay
Weed Science Laboratory, Institute of Agriculture, Visva-Bharati University.
Sriniketan 731236, West Bengal, India

Abstract: In South and South-east Asia the largest area under rice is transplanted and weed problem is less severe than in direct seeded rice. In east Asian countries of Japan and South Korea weed management is done by herbicides in almost all rice growing areas. In India, hand weeding is still most common method. In Punjab and Haryana non-traditional rice belt, where farmers are relatively rich and labour is scarce and costly, herbicide use is quite high. But in traditional rice belt in eastern India peasant farmers do not use much herbicide. With the general rise in labour wage there is a trend of increasing popularity to use herbicides in this region also. Herbicide use started in India with 2, 4-D and MCPA in the early fifties followed by propanil in the early sixties and thereafter broad spectrum herbicides like butachlor, benthiocarb, oxadiazon and pendimethalin came into use and are still more commonly used than other rice herbicides. Sulfonyl urea herbicides have recently shown promise for control of broad-leaf weeds and sedges. To solve the complex rice weed problem, a holistic approach of integrated weed management in rice based cropping system with lowest possible use of herbicides is needed to preserve environment quality. In addition, rotation of herbicides and herbicide combinations to prevent shift in weedflora and resistant biotypes, development of effective weed control technology for rainfed uplands, deep water and wild and red rice, low toxicity fast degradable and ecologically sound herbicides and alternative technique stressing non-chemical weed control methods including development of tools, biological methods and application of biotechnology are the important future lines of approach in rice weed control.

Key words: Integrated weed management, herbicides, nonchemical weed control, biotechnology, rice crop.

Introduction

World's rice land is situated in 111 countries with largest area in India(27.6%) followed by China(25.1%). Rice is cultivated in all countries in Asia, most countries of west and north and some countries in central and east Africa, four southern states of USA, most of central America and Latin America and Australia, Spain, Portugal, France, Italy and East European crountries. Highest average rice yield is produced in Japan, Australia, Korea and Spain.

In India, rice is the most important and extensively grown food crop occupying 41.6 m ha of nearly 41% of the total area of the cereals of the country with a total production of 76.6 m tonnes and average per hectare yield of 1744 kg (Fertilizer Statistics, FAI, 1993-94). It is cultivated in all the regions of the country under different kinds of rice culture. The traditional rice belt of India is the eastern states covering more than half of the total rice area of the country(53.3%) accounted only for 29.6% of the total annual production while the non-traditional rice belt in north western states of Punjab, Haryand and Uttar Pradesh with 19.8% of total area accounts for 40% of total production. The southern states of Andhra Pradesh, Tamil Nadu, Karnataka and Kerala accounts for 22,8% of rice production.

Basic types of rice culture in India include upland rice fully grown in rainfed dryland occupying 7.2 m ha and low land rainfed rice in which rice soil is puddled for transplanted or wet seeded and dry seeded followed by standing water due to rains. This ecosystem comprises of 4 sub-systems, viz. shallow submergence (0-30 cm), intermediate waters (30-50 cm), semi deep (50-100 cm) and deep waters (>100 cm). In eastern India, rainfed low land occupies 66% of the total area under this type of rice culture.

Upland rice weed problem :

Upland rice is primarily grown in tropical Asia, Africa and Latin America. In India, upland rice is mostly cultivated as unbunded rainfed in northern parts of West Bengal (*Aus* Paddy) and some parts of Assam (*Ahu* Paddy). Weed problems are far more complex and serious in dry seeded upland rice than in all the other rice production systems. In addition to severe weed problem due to simultaneous germination of crop and weed seeds and absence of standing water, there are also the added problems of inadequate and irregular rainfall and inefficient fertilizer use and sometimes lack of suitable varieties. Weeds can cause yield losses between 30 to 98% (Mukhopadhyay et al., 1972; De Datta and Llagas, 1982).

Mostly annual and some perennial weeds depending on the kind and density cause damage to the upland rice crop in India (table-1).

Table-1. Weedflora of upland rainfed rice in India

Botanical Name	Common Name	Life form*	Family
Grasses			
Echinochloa colona (L) Link	Jungle rice	(AG)	Poaceae
Echinochloa crusgalli (L) Beauv	Barnyard grass	(AG)	Poaceae
Eleusine indica (L) Gaertn.	Goose grass	(AG)	Poaceae
Dactyloctenium aegyptium (L) Willd	Crow foot grass	(AG)	Poaceae
Paspalam sp (L)	... ...	(AG)	Poaceae
Cynodon dactylon (L) Pers	Bermuda grass	(PG)	Poaceae
Digitaria sanguinalis (L) Scop.	Large crabgrass	(AG)	Poaceae
Sedges			
Cyperus rotundus L.	Purple nutsedge	(PS)	Cyperaceae
Cyperus iria L.	Rice flat sedge	(AS)	Cyperaceae
Fimbristylis miliacea (L) Vahl	... ...	(AS)	Cyperaceae
Broad-leaved			
Eclipta alba (L) Hassk	... ...	(AB)	Asteraceae
Trianthema portulacastrum L	Hors purslane	(AB)	Aizoaceae
Cyanotis axillaris (L) D. Don	... ...	(AB)	Commelinaceae
Digera arvensis Forsk	... ...	(AB)	Amaranthaceae
Bonnaya brachiata Link Otto	... ...	(AB)	Scrophulariaceae
Euphorbia hirta L	Garden spurge	(AB)	Euphorbiaceae

* AG : Annual grass; PG : Perennial grass; PS : Perennial sedge; AS : Annual sedge; AB : Annual broadleaf

Weed problem in low land rice :

The low land plains and river flood plains probably account for half to two-thirds of the total rainfed rice area. In these areas flooding and stagnant water are the most serious problem. Much of the rainfed rice in the low land plains and river flood plains of south and southest Asia is located in four major river deltas - the Mekong in Vietnam, Chaophraya in Thailand, Irrawaddy in Burma and Ganges - Brahmmaputra in India and Bangladesh. Two-thirds of the rainfed rice area in Asia is shallow rainfed (5-15 cm).

Rainfed low land rice in India, Bangladesh and Southest Asia generally cultivated in warm wet season (*Kharif*) as transplanted rice. In eastern India particularly in West Bengal and Bangladesh, this type of rice crop cultivated with standing water from rains in *Kharif* season is known as *Aman* rice.

Rice is cultivated in low land mostly as A) rainfed low land, B) irrigated.

A) Rainfed low land :

(a) dry seeded subsequently become flooded due to rainfall, (b) land is puddled and germinated seeds are direct seeded, (c) low land transplanted. In India unlike USA as in California, rice is never cultivated water seeded.

In case of dry seeded low land rice, weed problem is very severe at the initial stage and because of subsequent standing water due to monsoon rains weed growth is reduced at the later stages. Thus weed control measures are to be taken at the crital stage of crop growth namely before flooding to prevent the crop becoming weak initially.

In case of direct seeded puddled rice, because of puddling operation and thin flim of initial standing water weed growth is less severe than the dry seeded direct sown in upland rainfed or low land. But because of direct seeding and simultaneous germination of weeds and rice plants, the weed problem is comparatively more severe than transplanted rice.

In case of transplanted rice, weed problem is least severe not only due to check in growth of some weeds for continuous sub-mergence after puddling operation but also due to the fact that transplanting of rice seedling of higher age gives the crop an upper hand on weeds which are just germinating (Mukhopadhyay, 1978).

In transplanted rice, rainfed or irrigated, the hydrology of the rice yield, i.e., depth of water determines the composition of weed flora. In irrigated and shallow depth or water, *Echinochloa* sp., *Paspalum* sp., *Cyperus iria*, *Fimbristylis miliacea* are pre-dominant and above 2.5 cm water, *Sphenoclea Zeylanica*, are pre-dominant.

In the coastal saline areas of southern districts of West Bengal and Orissa, the algal weeds like *Chara zeylanica, Nitella* sp. and *Eriocaulon* sp. pose serious problem in rice field. (Mukhopadhyay, 1986 and 1988)

Mukhopadhyay (1990) reported major weeds in all kinds of low land rice system (e.e., rice with standing water from the beginning or at later stages (table-2).

Table-2. Weed flora of lowland rice in India

Botanical Name	Common Name	Life form*	Family
Grasses			
Echinochloa crusgalli (L) Beauv	Barnyard grass	(AG)	Poaceae
Paspalum scrobiculatum	Paspalum	(PG)	Poaceae
Sedges			
Cyperus iria L	Rice flat sedge	(AS)	Cyperaceae
Cyperus difformis L	Umbrella plant	(AS)	Cyperaceae
Fimbrystlis miliacea (L) Vahl	...	(AS)	Cyperaceae
Scirpus erectus Poiv.	Bulrush	(A/PS)	Cyperaceae
Scirpus supinus L	Bulrush	(AS)	Cyperaceae
Broad-leaved			
Sphenoclea zeylanica Gaertn	Goose weed	(AB)	Sphenocleaceae
Hydrolea zeylanica (L) Vahl	...	(AB)	Hydrophylaceae
Sagittaria sagitifolia L	Arrow Head	(AB)	Pontaderiaceae
Monochoria vaginalis (Burn f.) Presl	...	(AB)	Alismataceae
Sphaeranthus indicus L	...	(AB)	Asteraceae
Eriocaulon sieboldianum Sien et Zuce	...	(AB)	Eriocaulaceae
Ammania baccifera L	Red stem	(AB)	Lyraceae
Marsilea quadrifolia L	Pepper wort	(PB)	Marsileaceae
Ludwigia parviflora Roxb.	Water purslane	(AB)	Onagraceae
Aeschynomene aspera L	Joint vetch	(AB)	Papilionaceae
Algae			
Chara zeylanica Willd	Chara	..	Characeae

*AG : Annual grass; AS : Annual sedge; AB : Annual bradleaf; PG : Perennial grass;
PB : Perennial broadleaf; PS : Perennial sedge

B) Irrigated rice :

In north-west India, Punjab and Haryana, rice is cultivated as irrigated rice even in monsoon (summer wet) due to low rainfall, but in eastern India, rice is cultivated as irrigated crop only in summer season known as *Boro* and there is trend of increase in area under this *boro* crop due to higher yield then main warm wet season. While weed flora in north-west India comprises of usual *Echinochloa* spp. and other typical rice weeds but in *boro* rice, predominant weeds are sedge type namely, *Fimbristylis* spp., *Scirpus* etc.

Yield losses in low land rice :

The extent of yield reduction in rice due to weeds alone in India is estimated to be 15-20% for translanted rice and 30-35% for direct seeded rice under puddled conditions (Pillai and Rao, 1974).

C) Deep water rice :

Deep water rice are paddy fields experiencing water depth from 1.0 to 1.5 m atleast over a period of one month are included under deep and beyond 1.5 m under floating rice.

Deep water rice occupies 2.40 million ha in India, out of which 2.06 m ha is in eastern India. Yields of deep water varieties seldom exceed 1.0 t/ha. India has large deep water areas in Assam (0.1 m ha), Bihar (0.67 m ha), Orissa (0.13 m ha), Eastern U.P. (0.55 m ha) and West Bengal (0.67 m ha). In West Bengal the seed is broadcast in April-May in dry soil and weed competition occurs at the seeding stage.

Some time free floating aquatic weeds particularly *Eichhornia crassipes* and *Pistia* sp. invade deep water rice due to flash flood. Research information to control weeds in this hitherto unattended field of deep water rice is also necessary.

Critical period of weed management :

i) Upland rice : The first 15 days after seeding of upland rice seem to be the maximum period during which weed can be tolerated without affecting the final crop yield (Upadhyay and Chaudhury, 1979). The weed free requirement for upland rice varies from the first 20-60 days depending on edaphic and climatic conditions and weed flora (Sankaran and De Datta, 1985; Mukhopadhyay, 1989).

ii) Low land rice : In case of transplanted rice with the agro-ecology of standing water, the critical period of weed competition falls in the range of 25-55 weeks after transplanting (Gill, 1982, Mukhopadhyay, et al., 1992).

Weed Control Methods :

A) Non-Chemical Weed Control :

Land preparation :

Ploughing immediately after the various rice crops is harvested may have advantages over ploughing at the beginning of the next rainy season. Repeated tillage during the fallow periods prevents weeds from seeding and exposes propagulers to drying and significantly depletes weed seed reserves in the soil (Moody and Mian, 1979).

In some places in Srilanka and India, the land is prepared during the dry season. The rice seeds are broadcast on dry soil and covered. They remain dormant in the soil untill the advent of rain.

Land preparation and puddling in low land rice :

Land preparation during the dry season led to a significant reductiion in the number of *Cyperus rotundus* but had no effect on the annual grass population (IRRI, 1960). In India particularly eastern India, sometimes a pulse crop (*Kheshari - Lathyrus* sp.) is broadcast into the rice crop is 15-20 days to before harvest. As soon as the harvest is over, the pulse crop covers the fields in the dry season by its rapid vegetative growth. In India, during the dry season *Sesbania aculeata* is grown as a green manure crop and ploughed down before transplanting the next rice crop in the monsoon season. This results in lower weed infestation in the secceeding main crop (Mukhopadhyay, 1983).

Stale seed bed technique :

Stale seed bed technique in dry seeded upland rice involves the removal of successive weed flushes before planting. Chemicals (paraquat or glyphosate), mechanical and manual methods may be used to remove the weeds. The dry seeded rice crop may be sown with minimum of soil disturbance and the weeds are killed. Less weeds grow in association of rice because most of these in the favourable zone for germination have been killed (Moody and Mukhopadhyay, 1982 and Mukhopadhyay and Hossain, 1987).

Nitrogen application :

Weed growth is stimulated if nitrogen is incorporated into the soil. Nitrogen application should be timed to prevent weed proliferation and yet obtain maximum benefit from the fertilizer applied. With dry seeded rice, the basal application of fertilizer should be delayed (skipping basal dose of N) until weeds are removed (Evatt. 1965, Moody and Mian, 1979). That is the practice of farmers in many parts of India and Thailand (Moody & Mukhopadhyay, 1982).

In case of low land rice, topdressing nitrogen after weeding is desirable to maximize nitrogen fertilizer efficiency and to minimize weed growth (De Datta, 1981).

Plant spacing and seeding rate :

In all types of rice cultivar, close spacing in essential to minimize weed infestation and to obtain high yields - the closer the rice plants are sown, the better they can complete with weeds. Bhan (1968) found that narrow spacing (15 cm) was superior to wide spacing (30 and 45 cm) in minimising weed competition and increasing productive tillers and yield in upland rice.

Cultivar :

The wide spread replacement of traditional tall cultivars with modern cultivars may have increased weed problems throughout tropical Asia. Unlike the traditional cultivars that have droopy leaves, semidwarfs have erect leaves, more light penetrates the crop canopy and more weeds emerge and survive. Furthermore, the high fertilizer rates used on modern rice cultivars of medium stature may be better suited than semidwarfs. Even on experimental farms, intermediate statured IR 442-2-58 competed better with annual and perennial weeds than semidwarf IR-20 (De Datta, 1977).

Water Management :

About 80% of the rice grown in South and Southeast Asia is subjected to uncontrolled water supply, which exposes the rice land to various degrees of weed pressure (De Datta, 1981).

In dry-seeded wet land rice, there is heavy competition of weeds for moisture in the early stage when there is no standing water. In later stage of the crop when there is standing water from rains, water management is important. In direct seeded flooded rice, a depth of 10-20 cm water at the seedling stage reduces infestation of *Echinochloa crus-galli* (Smith and Shaw, 1966). Water management can substitute for weeding in transplanted rice. Grass weed problems can be completely eliminated if continuous 15 cm flooding is maintained throughout crop growth. Because of standing water in the monsoon in north eastern India, the rainfed transplanted rice crop does not have much competition from grass weeds (Mukhopadhyay, 1983). In north western India, even in the wet season it is not possible to maintain continuous subemergence because of scanty rainfall. Thus, irrigation and chemical or mechanical weed control are essential.

Crop rotation/cropping system

Rotation of crops breaks the association of particular weeds in a crop and minimizes the undisturbed development of weeds. Various component crops with different cultural practices in the rice-based cropping system reduces the difficult to control weeds (Mukhopadhyay, 1988).

Manual weeding :

i) Handweeding by hand tools :

In dry seeded rice in upland rainfed and in low land dry seeded at the early stage before impounding water, the most common and age old method of weeding in India and Bangladesh is by using a *Khurpi* or *Nirani* (small hand hoe) by human labour. This practice popularly known as "Hand Weeding", is very effective if done frequently, but it is extremely time consuming and involves huge amount of labour. Besides it has the drawbacks of being costly in many places, due to high wage rate and non-availability of labour for timely weeding.

ii) Rotary weeder :

For transplanted and direct-seeded flooded rice in India, the push type rotary weeder is used if seeding and transplanting are in straight rows.

In a 1966 study, the labour for 2 rotary weedings (115 hrs/ha) was half that for 2 hand weeding, but the grain yield was lower (De Datta, 1981). The slightly lower yield with the rotary weeding was perhaps caused by the inability of rotary weeding to remove weeds within or close to rice hills.

Mechanical weed control :

Farmers in some parts of Asia use mechanical weed control methods. For weed control in broadcast dry seeded rice (*Aus* Paddy) in Bangladesh and West Bengal, India, it is a common practice for farmers to pass a spike-toothed harrow through the rice fields 5-15 days after crop emergence (blind tillage).

In parts of India (Orissa and Madhya Pradesh) the farmers control weeds by ploughing and cross ploughing their fields after flooding when the rice is 30-40 days old. This practice was described as early as 1900s by Clauston (1908) and Graham(1913). The practice is known as *bueshening* in Orissa and *beasi* in Madhya Pradesh. This practice of *bueshening* needs to be replaced by more effective inter-row cultivation.

In India and Bangladesh broad casting is the common practice of seeding in upland or lowland dry seeded rice. This gives the difficulty of using inter-row equipments.

Thus, at a meeting on Research and Development in rainfed crop production in South and Southeast Asia, it was recommended that research for weed control should focus on tillage practices such as inter-row cultivation and other cultural practices. Such research should be directed toward modification of the native implements already in use before undertaking the design of new implements (FAO, 1978).

Further research is needed to determine if inter-row cultivation can be used successfully in dry seeded rice and if equipment that can work under a wide range of soil conditions. The possibility of using inter-row cultivation in combination with other weed control practices such as herbicides and hand weeding needs to be explored carefully.

B) Chemical Weed Control :

Herbicide use in India is little in traditional rice belt of north-eastern and south India, but it is quite popular in the north-western states of Punjab and Haryana (non-traditional rice belt). Chemical weed control in India is limited to areas where labour is scarce and wages rates are high. (Mukhopadhyay, 1992)

In India, herbicide use for both upland and lowland rice, started with 2, 4-D and MCPA in early fifties which controlled broadleaf and to some extent sedge weeds followed by use of propanil in early sixties for grass weed control and thereafter the broad spectrum herbicides like benthiocarb, oxadiazon, pendimethalin have come into use and continue still to be the most commonly used herbicides over other rice herbicides. (Mukhopadhyay, 1993)

However herbicide which are exclusively used for rice with standing water mainly transplanted rice are anilofos, cinmethylin and sulfonyl ureas.

Table -3. Herbicides in use in India under different rice culture :

Situations	**Herbicides** **Dose Kg.a.i/ha.**
1. Rice Nursery	Oxadiazon 0.5 kg, Butachlor 1.0 kg, Thiobencarb 1.0 kg as pre-emergence
2. Upland dry seeded rice	Oxadiazon 0.5 kg, Pendimethalin 1.0 kg Butachlor 1.5 kg, Thiobencarb 1.0 kg
3. Rice with standing water (Transplanted, direct seeded puddled and low land direct seeded).	Butachlor 1.0 kg, Pendimethalin 1.0 kg, Thiobencarb 1.0 kg, Anilofos 0.4 kg, Pretilachlor 0.25 kg, 2,4-D EE(G) 0.5 kg, Oxyfluorfen 0.10 kg, Fluchloralin 1.5 kg **Newer herbicides:** Cinmethylin 60-80g 10 DAT, Quinchlorac 0.2-0.3 kg 3-5 DAT **Sulfonyl ureas:** Met-sulfuron methyl 2-4g 12 DAT Chlorimuron ethyl 6-12g 12 DAT Thiobencarb methyl 7.5-15g 12 DAT Tribenmuron methyl 7.5-15g 12 DAT Bensulfuron methyl 0.5 kg 12 DAT

N.B. Propanil, Nitrofen are off the market in India.

Biological Control :

Research into biological control of weeds by insect, pathogen, fish, snails etc. have made some progress. In India, except some use in controlling aquatic weeds *Salvinia* sp and *Eichhornia* sp, weed control in rice by biotic agents have not yet become popular. Whatever little published information on successful weed control by bioagents in rice have been reported are presented in table-4.

Table4. Biological weed control in rice

Rice Weed	Bioagents	References
Echinochloa crus-galli	*Drechslera monoceras* (Fungus) *Fusarium oxysporum* (Fungus) *Leptosphaeria salvinii* (Fungus)	Gohbara, 1991 Arita, 1990 Nishi, 1988
Echinochloa cryzicola	*Dreschslera poae* (Fungus)	Arita, 1992
Echinochloa colona	*Dreschslera ravenclii*	Gohbara, 1992
Echinochloa sp.	*Lymnocea* sp. *Physa* sp. (Snails)	Gohbara and Yamaguchi, 1993 "
Eleocharis kuruguwai	*Epicoccosorus nematosporus* *Nimbya scirpicola* *Dendryphiella* sp.	Suzuki, 1990 Shibayama, 1992 Imaizumi, 1992
Eichhornia crassipes	*Neochetina eichhornae* (Insect) *Neochetina bruchi* (Insect)	Julien, 1992
Salvinia molesta	*Cyrtobagous salviniae*	Room. 1990
Ageratum conyzoides	*Hirschmanniella spinicaudata* (nematode)	Babatola, 1980
Monochoria vaginalis	*Azolla pinnata* (Fern)	Mansor and Lang, 1993
Alternanthera philoxeroides	*Agasicles hygrophylla*	Zeiger, 1967
Cyperus rotundus	*Athesapaeuta cyperi* *Bactra minima minima*	ICAR Biological Control Centre India Tech. Bulletin. 1, 1989
Algal weeds	*Pomacea canalieulata* (Insect)	Chiang, 1993
Ludwigia adscendens	*Haltica caerulea* *Monophycs* sp. var. *Nigritulus* (Insect)	ICAR, Biological Control Centre India Tech. Bull. 1, 1989
Pistia stratiotes	*Namangana pectinicoris*	"
Algal weeds	*Pomacea canaleieulata*	Chiang, 1993

Future lines of weed management in rice :

1.Monitoring of weeds - shift in weed flora, appearances of resistant and introduction of new weeds :

Continuous use of herbicides or use of the same herbicide year after year has created the problem of succession of weeds and appearance of resistant biotypes of the same weed. Propanil herbicide, once very effective against *Echinochloa* sp., is now ineffective against the biotypes of this weed. A trend of succession from grassy weeds towards sedge and broadleaf weeds in rice fields has also been evident. Systematic monitoring of weeds would help to devise effective ways to tackle this growing problem.

2. Emphasis on ecological, biological and other non-chemical methods weed control for environmental safety :

Standardisation and perfection of research on various ecological and promising biological methods as well as non-chemical cultural methods for avoiding the environmental hazards of chemical method of weed control has to be made.

Further research to determine the extent of effectiveness agronomic manoeuvring like stale seedbed, nitrogen management, water-management, crop rotation and modification of native hand tools for weeding is needed.

3. Rice based cropping system wise integrated weed management approach :

Need for shifting research towards weed management in rice based cropping system as a whole from the existing research to find weed control technology for individual crops.

In different agroecological regions of India large number of different rice based cropping systems with various component crops are practised. It is necessary to study the possible effects of weed control practice in rice on the succeeding crops on the lines of a) reduction of density in succeeding crops, b) changes in floristic composition or shift in weed species and c) problem of selectivity and residual toxicity of herbicides in the cropping system.

4. Develop threshold research in weed management in rice :

From field research data on weed density and duration of interference on the crop, competitive threshold needs to be worked out and its relation to monetary yield losses would bring out the economic threshold.

Unlike insect and disease control, little or no research has been done on economic threshold levels in weed control in rice or other crops.

5. Rotation of herbicides and herbicide mixtures :

More research information and a thorough understanding about the interaction among currently used herbicides when used in mixtures, their compatibiliity, selectivity and bio-efficacy as also problems of phytotoxicity and persistance is needed. Similarly necessity of rotation of herbicides to solve the problem of weed flora shifts and appearance of resistant weeds.

6. Develop more effective weed control technoligy for rainfed upland rice

Inspite of large volume of research on weed control in rainfed upland rice, effective and sound weed control technology in this type of rice culture is still lacking because weed problems are far more complex and serious in dry seeded rainfed upland rice than in other rice production systems in tropical Asia. Recognising this alarming weed situation, basic and applied research to help develop weed control technology suitable for a wide variety of local condition is needed.

7. Develop weed control technology for wild and red rice :

Wild and red rice as weeds are a serious threat to rice production in many countries in Africa, Latin America and Thailand. The wild rice species namely *Oryza longistaminata, O. breviligulata and O. glaberrima* invade rice field and red rice species normally belongs to the same species as cultivated rice

(O. sativa). Another red rice species is *O. rufipogon Griff.*

Although it has been reported that red rice problem can be minimized by growing rice in puddled continuous flooding condition as well as late seeding or transplanting (Sonnier, 1978, Vongsaroj, 1993). The fact is that so far no solution to wild and red rice problem has been achieved.

8. Develop low toxicity fast degradable eco-friendly and safe herbicides :

New herbicides like cinmethylin (40-80 gm a.i./ha) (Argold) and sulfonyl ureas (7.5-10 gm a.i./ha) are effective in low quantities and have little or no residual toxicity. (Mukhopadhyay and Banerjee, 1989 and Mukhopadhyay and Mallick, 1991)

Cinmethylin being made up of carbon, oxygen and hydrogen has very low toxicity to mammals, birds, fish and other aquatic organisms.

AC-382 140 broad spectrum safe new herbicides for transplanted rice in Japan and Philippines have been reported to show promise (Quakenbush *et al,* 1993).

Biotechnology in rice weed management :

Application of biotechnology can play a great role to solve the emerging problems of chemical weed control by standard herbicides. This area needs to be further developed for safe and alternative weed control (Mukhopadhyay, 1992). The microbial toxins and allelochemicals provide novel chemistries that could be manipulated to produce commercial herbicide. Bio-herbicides (*Collego* for rice weed control), naturally occurring herbicide (*Bialopas* with active ingredient phosphinothricin to control grass and broad leaved weeds) and *methoxyphenone* (a synthetic analog of the microbial toxin anisomycin to control branyard grass in rice). To overcome the low virulence of the pathogen and the required fastidious environmental conditions for development of bio-herbicides, genetic manipulations like recombinant DNA technology of and integration of bio-herbicides with chemical herbicides may be done to enhance the activity. In India, bioherbicides for weed control has not developed for practical application.

Acknowledgement : Appreciation is expressed to co-research workers in my Weed Science Laboratory particularly R.B. Mallick, A. Hossain, D.C. Mandal and Prabir Mukhopadhyay for assistance in preparation of the paper. Sincere help of the Visva-Bharati Computer Centre for camera ready preparation of the manuscript is acknowledged.

References

Arita, M. 1990. Japanese Patent Application No. 02-13367 (In Japanese).

Arita, M. 1992. European Patent Application. Publication No. 0 374499 A European Patent Office, Munich, Germany.

Babatola, J.O. 1980. Weed Res. 20. 59-61.

Bhan, V. M. 1968. Weed Control in field crop culture at Pantnagar, India. Pans. 14 : 235 - 261.

Chiang, M. Y. 1993. Integrated management of Paddy weeds in Taiwan. Food and Fertilizer Technology Centre, Extension Bulletin No. 368.

Clouston, D. 1908. The transplanting of rice in Chatisgarh. Agric. J. India. 3 : 338-356.

De Detta, S. K. 1977. Weed Control in rice in Southest Asia : Methods and Trends. Philipp. Weed Sci. Bull. 4 : 39-65.

De Datta, S. K. 1981. Principles and Practices of rice Production John Wiley and Sons, New York. p 460-507.

De Datta, S. K. and M. A. Llagas, 1982. Weed Problems and Weed Control in upland rice in tropical Asia, Paper presented at the Upland Rice Workshop, Bouake, Ivory Coast, 4-8 October, 1982.

Evatt, N. S. 1965. The Mineral Nutrition of Rice Plant. The John's Hopkins Press, Baltimore, Maryland, pp 243-253.

FAO (Food and Agricultural Organization). 1978. Report on the Export consultation on rainfed crop production research and development in South and Southest Asia. FAO - RAFE 32-85 p.

Fertilizer Statistics, FAI, 1993-94. The Fertilizer Association of India, New Delhi, pp-III 28-30.

Gill, H. S. 1982. The role of hand and mechanical weeding in weed management in advancing countries - Improving Weed Management, FAO, Plant Production and Protection Papers, 44, FAO, Rome, pp 17-22.

Gohbara, M. 1991. Japanese Patent Application No. 03-219883 (In Japanese).

Gohbara, M. 1992. European Patent Application, Publication No. 0 464416 A 3, European Patent Office, Munich, Germany.

Gohbara, M. and K. Yamagushi, 1993. Biological agents for the Control of Paddy Weeds in Japan. Food and Fertilizer Technology Centre. Extension Bulletin No. 369.

Graham, R. J. D. 1913. Preliminary note on the classification of rice in the Central Province. Mem. Dep. Agric. Indian Bot. 7(7).

ICAR, 1989 Biological Suppression of Weed Technical Bulletin No. 1, NCIPM pp 1-27.

Imaizumi, S. 1992. Annals of the Phyto-pathological Soc. of Japan. 58, 1 : 158 (In Japanese).

IRRI (International Rice Research Institute), 1980. Annual Report for 1979. Los Banos, Philippines, p.538.

Julien, M.H. 1992. Biological Control of Weeds. A World Catalogue of Agents and their target weeds. 3rd Edition. CAB International, Washing Walling Food England. p.186.

Mansor, M. and N. T. Lang, 1993. The biology of Monochoria vaginalis and its control by Azolla pinnata. Abs. 10th Australian and 14th Asian Pacific Weed Conference. Brisbone, Australia, Sept. 1993, p. 38.

Moody, K., A. L. Main, 1979. Weed Control in Rainfed Rice. International Rice Research Conference. IRRI, 1978. pp 235-245.

Moody, K., S. K. Mukhopadhyay, 1982. Weed Control in Dry Seeded Rice-Problems, Present Status and Future Research Directives, IRRI, pp 147-158.

Mukhopadhyay, S. K. 1978. Weed Problem in lowland rice under sub-emergence, Proceedings National Symposium on increasing rice yield in Kharif, ICAR and CRRI, Feb. 3-11, 1978, pp 301-310.

Mukhopadhyay, S. K. 1983. Weed Control Technology in Rainfed Wet Land Rice in "Weed Control in

Rice", IRRI and IWSS, IRRI, Los Banos, Philippines. pp 109-118.

Mukhopadhyay, S. K. 1986. Noxious Aquatic Vegetation in W. Bengal. Indian Agric. 30(2) : 153-160.

Mukhopadhyay, S. K. 1987. Weed Management in rice and rice based cropping systems. Proc. Pak-Indo-US Weed Control Workshop and First Annual Conf. Pakistan Soc. Weed Science, pp 198-212.

Mukhopadhyay, S. K. 1988. A methodology for on farm weed control Trial in rice fields of the coastal areas of West Bengal. Farming System Res. News Letter. RKM/LSP/FSR, Narendrapur III (3) : 20-21.

Mukhopadhyay, S. K. 1988. Weed Dynamics in rice and rice based cropping systems. Abs. of Papers National Symp. Changing Pest Situations in currest agricultural Scenario of India. IARI, May 14-16, 1988 (ICAR and ISAS, India).

Mukhopadhyay, S. K. 1990. Weed Management in rice ecosystem in India. Proc. Agric. Eco-System Management, pp 327-335, Visva-Bharati University, Institute of Agriculture, W. Bengal, India.

Mukhopadhyay, S. K. 1992. Applicatiion of bio-technology in weed control "Resource Management for Sustained crop Production". Proc. National Symposium on Resource Management for Sustained crop Production Organised by Indian Soc. Agron. at Bikaner. Rajasthan Agric. Univ. Feb. 25-28, 1992 pp 63-66.

Mukhopadhyay, S. K. 1992. Emerging problems and advances in weed Management. Presidential Addresses, Agric. Section, 79th session of the Indian Science Congress at Baroda. (Jan. 3-8, 1992) pp. 1-16.

Mukhopadhyay, S. K. 1993. Weed Research in India and Future Thoughts. Proc. 14th Asian Pacific Weed Sci. Soc. Conf. Brisbane, Australia, 6-10th Sept. 1993. Abs. of Papers. p-47.

Mukhopadhyay, S. K., A. B. Khara and B. C. Ghosh, 1972. Nature and Intensity of Competition of Weeds with direct seeded upland IR-8, Rice, FAO, International Rice Commission News Letter XXI (2) : 10-14, 1972 (Bangkok).

Mukhopadhyay, S. K. and A. Hossain, 1987. Weed Control in Upland Rice by Non-Chemical Methods. Abs. Proc. 11th APWSS Conf., Taiwan, p 62.

Mukhopadhyay, S. K., A. Hossain and Rita Modak, 1992. Crop Weed Competition Studies in Transplanted Rice. Abst. Ann. Weed Sci. Conf. (ISWS) at Hissar. March 3-4, 1992. pp 9 (Abst. 2.1).

Mukhopadhyay, S. K. and K. Banerjee, 1989. Effectiveness of the new herbicide - Cinmethylin in controlling weeds in rice. Proc. 12th Asian Pacific Weed Sci. Soc. South Korea, pp 21-26.

Mukhopadhyay, S. K. and R. B. Mallick, 1991. Metsulfuron, Chlorimuron and Tribenuron in low dose high efficiency herbicides for weed control in transplanted rice. Proc. 13th Asian Pacific Weed Science Soc. Conference. pp (157-1663). Jakarta, Indonesia.

Nishi, K. 1988. Dressess Diseases of barnyard grass, Weed Res. (Japan) 33 : 163.

Pillai, K. G. and M. V. Rao, 1974. Paper Presented at the International Rice Research Conference, IRRI, 1974.

Quakenbush, L. S., S. J. Roadway, B. Tecle, T. E. Brady, B. Lapade, P. Marc, M. S. Condon and T. Malafyt, 1993. AC - 322, 140 - a new broad spectrum herbicides for selective weed control in transplanted and water seeded rice. Abs. 10th Australian and 14th Asian Pacific Weed Conference. Brisbane, Australia, September, 1993. p-57.

Room, P. M. 1990. Ecology of simple plant herbicides herbivore system. Biological Control of Salvinia. Trends in Ecology and Evolution. 5 : 74-79.

Sankaran, S., S. K. De Datta, 1985. Weeds and Weed Management in Upland Rice. Advances in Agronomy, 38 : 283-337.

Shibayama, H. 1992. Weed Res. (Japan) 37 : 188.

Smith, R. J. Jr. and W. C. Shaw, 1966. Weeds and Their Control in Rice Production. USDA Agric. Hand b. 292, Washington, D.C. 64 p.

Sonnier, E. A. 1978. Red Rice Studies, Pages 131-142 in Rice Experiment Station, Louisiana State University and U. S.Department of Agriculture. 70th Annual Progress Report.

Suzuki, H. 1990. Biological Control of a Paddy Weed, Water Chestnut, with a fungal pathogen In : The Biological Control of Plant Diseases, FFTC Book Series No. 42. Food and Fertilizer Technology Centre for the ASPAC Region. Taipei, Taiwan ROC, pp 78-87.

Upadhyay, U. C. and B. S. Chaudhury, 1979. Studies on weed management in upland paddy. Proc. 7th Asian Pacefic Weed Sci. Soc. Conf., Sydney, pp 289-291.

Vongsaroj, P. 1993. Integrated Management of Paddy Weeds in Thailand Food and Fertilizer Technology Centre. Extension Bull. No. 367, p-13.

Zeiger, C. F. 1967. Biological Control of Alligator Weed with Agasicles n. sp. in Florida. Proc. Southern Weed Conf., 20 : 299-303.

Noxious Weeds in Asian Tropics and their Control

U. Suwunnamek
Department of Agronomy, Kasetsart University, Bangkok, Thailand

Abstract. Noxious weeds usually possess some characteristics in common, e.g., rapid multiplication, adaptation to changing circumstances, high competitive ability, and resistance to control measures. Dormant tubers of *Cyperus rotundus* L. which are small and hard to identify make the weed a serious one in the same way as a piece of rhizome of *Imperata cylindrica* (L.) Raeuschel in the soil. The tuber or rhizome if under unfavorable condition it stays dormant underground. With its high competitive power and resistance to most preemergence herbicides plus its irritating hairs on leaves when touched, *Rottboellia cochinchinensis* (Lour.) Clayton is considered very serious in any crop.
Management of weed species mentioned above is discussed in the paper.
Key words: *Cyperus rotundus*, *Imperata cylindrica*, *Rottboellia cochinchinensis*, noxious weeds.

Introduction

Perhaps many people wonder what noxious weed is. WSSA (38) defined that a plant regulated or identified by law as being undesirable, troublesome, and difficult to control. Mercado (20) described noxious weeds as those which are highly competitive, persistent, and are difficult to control. She also mentioned five major characteristics which contribute to their aggressiveness and persistence. However, Cardenas et al. (6) divide noxious weeds into two categories, the primary and the secondary. Primary noxious weeds are those which are widely distributed and established in a region, are very aggressive and difficult to control. Secondary noxious weeds are defined as either: (a) those which are aggressive, widely distributed and established in a given region, but are relatively easy to control, or (b) those which are aggressive and difficult to control but may not yet have become established. They also defined common weeds as those which are easy to control and in general, although well distributed, are not aggressive. So, aggressiveness (e.g., a plant with rank growth, rapid multiplication, and/or with highly competitive ability, or a plant equipped with harmful organs or toxic substances) and tolerance substances) and tolerance to adverse environmental conditions (including control measures) are the key factors to determine whether it is noxious or not. In general, noxious weeds are noxious in many to most crops but may not necessary to be in all crops. This is due to the difference of crop nature, cultural practices, and especially the herbicide use.

Actually there are a lot of noxious weeds in Asian tropics to be mentioned but only three species are selected to suit time and pages allocated.

Cyperus rotundus L.

Common name: Purple nutsedge. Family: Cyperaceae

Origin. It is a native in India and now a weed in 52 crops in 92 countries in the tropics and subtropics areas (11).
Description. A perennial sedge with tuberous base producing rhizomes which later on give off tubers which may or may not develop shoots. Culm : slender, triangular same as most sedges, 15 to 50 cm tall. Leaves : erect, glabrous, linear, grass-like, 5 to 30 cm long and 2 to 6 mm wide. Inflorescence : simple or compound umbel with spikelet clustered at the tips of branches, 1 to 3.5 cm long and 2 mm wide containing 10 to 40 flowers, and protected by reddish brown glumes with 5 to 7 nerves.
Reproduction. The weed mostly reproduce itself from tubers. Tuber germinates under appropriate conditions by giving off sprout or short rhizome that begins a new shoot, and a basal bulb develops just under the ground line. The basal bulb later on forms a new rhizome and becomes a new plant again (30). Single tuber can produce 39 tubers

in 4 months under favorable condition (1). Under field condition it produced about 4 times of the original counts (from 120 tubers/0.25 m^2 and 20 cm deep) in a year (35). There are many reports that tuber production is much more than this (21). By this mechanism plus tuber dormancy make the weed survive even extreme conditions.
Problem. Infestation of *C. rotundus* mostly occurs in cultivated fields, and especially where herbicides are used repeatedly or routinely. So far in Thailand, infested crops are field corns, sugarcane, soybean, sorghum, and also lately vegetables, e.g., shallot, garlic. Modern field crop plantations and especially seed production fields have the problem. For the latter they use herbicides because they need weed-free conditions to facilitate intensive farm practice, and also at the same time they do not want the seeds which cost more than ten times of grains contaminated with weed seeds. The problems in soybean is slightly different. This is due to its tubers in paddy field have not been killed by water level and when soybean is planted no-tillage after rice the infestation resumes. Again, herbicides used in soybean cannot control nutsedge. *C. rotundus* also causes problem in lawns and green in golf course. Nutsedge plant grows faster after mowing comparing with the grass.
Competition. *C. rotundus* usually absorbs more nutrients than the crop. Nutsedge plants growing with cotton at 5:1 weed crop ratio can take up about twice as much N, one-third more of P. and three-fourth more K from the soil compared with cotton (10). However, crop species and even cultivars as well as seasonal changes dictate the severity of the weed. Full season competition with *C. rotundus* population ranging from 600 to 1600 plt/m^2, caused 35 to 89% losses in vegetable crops in Brazil (40). Garlic is ranked first followed by okra, tomato, and carrot. Upland rice is often seriously competed by nutsedge. In Thailand for sweet corn ear weight was significantly reduced by low density of nutsedge plants (10 to 20 shoots/0.25 m^2) compared with weed-free in dry season, but not in wet season during which the medium density (20 to 40 shoots) reduced the yield. Gain yield of field corn Suwan 1 was significantly reduced by medium density of nutsedge in dry season but required high density (50 to 80 shoots) for the reduction in wet season. There were also different responses among field corn cultivars (1).
Management. Established infestation of *C. rotundus* is very difficult to practically eradicate. Only temporary control from crop to crop with quite high cost of handling or with more steps of operation can be made. In planting management a few weak points of the weed should be realized: 1) shoot and tuber production is greatly reduced by 20% light intensity (21), 2) tubers having been soaked in water for 200 days still retain full viability (7), 3) dried tubers with moisture content 12% (72 hr sun-drying) are unlikely to germinate (25). So, practically management should integrate many methods together, i.e., preventive measures, physical control, habitat management, and also chemical control.

Preventive measures, see in conclusion.

Physical control includes cultivation for land preparation, inter-row tillage (once or twice times), and post-harvest following. The practices at least can turn over tubers to drying and germination decreased. Thorough disking at 2 to 3 weeks interval for growing seasons was recommended to eradicate *C. rotundus* (39). For small area forking to take out the bulbs or tubers is effective, but very laborious job.

Habitat management employs techniques on environment to reduce or eliminate competition of the weed. Size and nature of crop plant, density per unit area and its response to the environment should be considered first.

Crops which can complete with nutsedge should grow fast and produce shade enough to suppress the weed. Even though mulching with rice hull or sawdust is not effective, but with thicker layer new plants will develop within the layer and easy for hand pulling. The method is suitable for small area.

Chemical control is so far the main tool for the seriously infested area to keep it calm down during crop season. Even though there are a number of herbicides effective on *C. rotundus* (21) only those familiar and practically used in the tropics are to be mentioned.

Glyphosate and also sulfosate, translocated and non-selective chemicals, are quite effective for the weed at 2.25 kg ae/ha. Lower rate at 1.13 or 1.69 kg ae/ha can work too if combined with ammonium sulfate 10 kg/ha at the spray volume of 500 L/ha (1). C. rotundus should applied at 3 weeks after emergence of tubers, and mostly as preplant treatment in no-tillage method in any crops. Generally, residual activity is none, but in certain crops and soils careful study should be conducted in advance to make sure of the safety.

2,4-D is also translocated and selective for control of broadleaves in graminaceous crops. As overall spray at 2 kg ae/ha (quite high) for control of nutsedge in sweet corn at 25 days after planting, 2,4-D also gave quite a good result (1). If as preplant treatment it should be combined with 10 kg urea (35). Rate for some crop should be reduced. Some tubers are killed by 2,4-D but with less percentage than glyphosate.

Arsonates (DSMA, MSMA), even with some translocation, the chemicals should be regarded as the contact and with only top kill. MSMA can also be used to control grasses in cotton and lawn (18).

Chlorimuron is the herbicide belongs to sulfonylurea group for control of broadleaves and sedges. At 30 g ai/ha it was effective when applied preemergence in soybean. Chlorimuron 12 g ai combined with glyphosate 1.5 kg ai/ha applied preplant gave enough control of nutsedge (2 wk old) in soybean without affecting yield (9).

Imidazolinone herbicides (imazaquin, imazethapyr, and imazapyr), are also effective for *C. rotundus*. Imazaquin and imazethapyr were both effectively used as preemergence in soybean at 420 and 125 g ai/ha, respectively. Imazaquin 280 g ai/ha combined with glyphosate 1.5 kg ai/ha applied preplant also provided an adequate control of the weed (2 wk old) in soybean. Even though imazapyr at 40 g ai also gave the same degree of control, but it decreased soybean yield (9). Imazapyr possesses long residual activity ranges from 3 months to 2 years under field conditions and it is nonselectively used in noncropland (38).

Uses. Nutsedge tubers can be used by its own or as an ingredient in quack remedies of antidysenteric and carminative (suffering from flatulence) (22). In agriculture, for ridged plantation (e.g., citrus) in the low land area of Thailand, it has been observed that the growers grow *C. rotundus* on the bank to prevent erosion.

***Rottboellia cochinchinensis* (Lour.) W.D. Clayton**

Common name: Itchgrass. Family: Poaceae (Gramineae)

Origin. The grass is a native to India, a weed in 18 crops in 28 countries within 20°C isotherms in the northern and southern hemisphere (11).

Description. An aggressive annual grass belongs to tribe Andropogonaceae. Culm : stout with still roots, hairy, erect branched, 1.5 to 2.5 m high; tiller produced ai the basal nodes, branches arise at the axils of upper leaves. Leaves : linear-lanceolate, about 1 m long, and 2.5 cm broad, tapering to each end, pale green color with well marked white midribs and rough sharp edges; sheaths bear with white bristles which can cause irritation when contact with skin. Inflorescence : spike-like, with cylindrical spikelets in pair compressed against the rachis and tapering towards the apex; spikelet glabrous and awnless, one sessile and the other on small stalk. Fruit : cylindrical caryopsis containing seed, at maturity fall off from the apex to the base.

Reproduction. The weed reproduce by seeds in large number ranging from about 4,500 to 50,000 seeds/plant/cycle depending on the growing season. Seeds possess dormancy which is due to the presence of hull and immature embryo also. Intact seeds were found to germinate 1 and 7 % after 8 and 12 months of storage at room temperature, respectively, meanwhile dehulled seeds germinate 56 and 85% respectively (14). Under field condition dormancy period could be less than this. However, some seeds are still viable even more than 2 years in the soil if the condition is not suitable (19).

Problem. The grass is a problem in upland and plantation crops in certain area once it gains a foothold there by any means. It is very competitive and we can observe that it tends to dominate other weeds, even the very serious one like *Imperata cylindrica* (L.) Raeuachel and it will be easy if the weeds are low growing like *Cyperus rotundus*. So, we can find the grass both in cropland and non-cropland. It a is serious weed in sugarcane in the Philippines, Indonesia, Malaysia, and Thailand (29). Problem and causes can be summarized: 1) due to its dormancy which keeps the seeds germinate ceaselessly after the earlier flash has been controlled, 2) seeds can germinate even from deep soil germinate more than 50% from 20 cm deep, 3) bristles on leaf sheaths and blades causes severe itching to workers handling the weed or crop, 4) it is impossible to get rid all of the weed by normal routine operation, and this can cause unending infestation, 5) other than highly competitive ability, nobody want to go into the infested areas, and that can cause more loss in crop production.

Competition. Study with soybean showed that even a single plant of itchgrass in one m^2 can cause significant reduction of yield (more than 30%) in wet season growing, but not in dry season which needs two plants to reduce the yield. Sixteen plants caused 65% yield reduction in wet season but only 25% reduction in dry season (14). The season for the difference is that the weed did not grow very well in dry season which the plant height is about 60 cm compared with 165 cm in wet season. Another reason is that soybean plants grew much better in dry season compared with those in wet season. Crops respond to itchgrass differently. Study with field corn in late wet season shows that 5 and 40 plt/m2 of the grass caused yield reduction 8 and 43%, respectively (33). Compared with soybean mentioned above, field corn are more tolerant of itchgrass. Competition study shows that field corn can tolerate itchgrass for 2 week at density 80 plt/m^2 but this same length of time soybean can tolerate only 16 plt/m^2.

Study on area of influence of itchgrass in soybean, it was concluded that the grass can reduce seed yield significantly, more than 30% if it grows close to crop plant at the distance of 7.5 cm and 50 cm in dry season (14). It is surprised that the effect seems much higher compared with the report in which soybean seed weight within 20 cm of the weed was reduced only 15 to 21% (17). However, there are a number of biotypes of itchgrass and each responds differently to the varied weather condition . This could be a reason.

Management. Actually preventive control should be born in mind where one is farm has high potential to be under threat of the grass (see in conclusion).

In newly infested areas, eradicative measures are inevitable. Successful eradication of the grass was expected to be obtained in three years or 18 months at least, so far as the areas were regularly checked and the weed plant removed all the time before seeding (19). Studies by Richards and Thomas (26) have shown the persistence of its seeds in the soil to be three years at the utmost.

Unlike purple nutsedge, itchgrass is not sensitive to shades. So, growing crops like soybean or field corn to suppress the weed's growth is not successful. Even growing legume cover crops we have to help them at the beginning until they form a thick bush to suppress the grass. So far, less herbicides can be used in corn (practically only preemergence herbicides) whereas more can do with legume crops. So, crop rotation with legume or other crops which both preemergence and a number of postemergence herbicides can be effectively used could indirectly help decrease the infestation.

Interrow cultivation (disking, off-barring and hilling up) can be used in row crops. However, it should be followed by hoeing, especially these in the row.

Herbicides play a key role in dealing with itchgrass as well as in indirectly spreading the grass. Very few residual chemicals can be used effectively on itchgrass, and among these are herbicides belong to dinitroaniline group, e.g., pendimethalin, trifluralin, dinitramine, etc (19). Pendimethalin is quite well known and easy to use in many crops. It can control other grasses as well at 1.5 to 2.5 kg/ha, but not much effective for certain broadleaves, e.g. *Euphorbia heterophylla* L. The chemical if combined with atrazine at 1.5 kg/ha each was quite effective in corn (34). In sorghum application should be at 2 weeks after crop emergence and also after destroying the first flush of seedlings. In soybean a good weed control was obtained with pendimethalin alone at 2.2 kg/ha and also with the combination of imazethapyr at 150 g/ha plus oxyfluorfen 250 to 500 kg/ha or clomazone 75 to 150 g/ha without affecting yield (14).

For foliar-applied herbicides, it was found that most aryloxyphenoxy alkanoic herbicides are effective (14), i.e., quizalofop-tefuryl and quizalofop-ethyl, fluazifop-butyl, haloxyfop-methyl, and fenoxprop-ethyl at 0.25 to o.5 kg/ha. In soybean, double applications at 3 and 6 weeks after crop emergence can decrease weed population, and hence with the increase in grain yield. However, still there was a new flush of seedlings coming up. Preemergence application of herbicide followed by postemergence application performed similarly.

Diclofop-methyl and cyclohexanedione herbicides e.g., clethodim, cycloxydim, and sethoxydim, did not provide a satisfactory control (34).

Nicosulfuron is also active for itchgrass in field corn as directed spray, but overall application is still not satisfied. Ametryn at quite high rate, 4 kg/ha plus surfactant, also can work as well as glyphosate, glufosinate, asulam (34) MSMA, DSMA, paraquat, and others (19).

So, itchgrass in cropland and noncropland, if not too long established, should pose no problem as there are many herbicides or means which can be selected to suit the situation.

Use. Some biotype of itchgrass which is not much hairy and less itching sensation, and does not germinate in dry season, can be grown in wet season, especially in lowland areas. By dry season as the plant is almost 2 m high and seeds mature. It is pressed to the ground, and then vegetable crop seedlings, e.g., cabbage, Chinese cabbage, kale are transplanted no-tillage. Itchgrass plant mulch can preserve moisture and keep off other weeds as well as itchgrass itself. In most cases people can grow twice crops before the rain comes

***Imperata cylindrica* (L.) Raeuschel**

Common name : Cogongrass. Family : Poaceae (Gramineae)

Origin. A native of the old world, it is on all of the continents and is the worst weed of southern and eastern Asia. Seventy-three countries report that it is a weed in 35 crops (11).

Description. Perennial grass, compact or loosely growing. Culms : erect, 15 to 120 cm high, arising from an extensive system of tough, scaly rhizomes, unbranched. Leaves : linear-lanceolate, up to 150 cm long, 4 to 18 mm wide : sheaths smooth or margins ciliates : ligule short, truncate, 0.5 to 1 mm long. Inflorescence : panicles, dense, and spikelike, 3 to 20 long, 0.5 to 2.3 cm wide, creamy-white or silvery-white silky hairs : spikelets 3 to 6 cm long surrounded by silky hairs 10 mm long. fruit : a caryopsis, 1 to 3 mm.

Reproduction. Propagation is by seed or vegetatively from numerous rhizomes.

Varieties. *I. cylindrica* is widely distributed between the latitudes of 45 ° in both the northern and southern hemisphere. Following the examination of a large number of specimen. Rubbard et al. (12) placed them in five major groups:

1. var. *major* is most widely distributed from Japan, southern China through the pacific Islands and Australia to India and eastern Africa.
2. var. *africana* is the next most widely distributed from Senegal and Sudan southward through Africa.
3. var. *Europa* extends from Portugal through southern Europe to the arid regions of Central Asia and Afghanistan.
4. var. *latifolia* is found only in northern India.
5. var. *condensata* is found in Chile on the coastal region between lat 30 ° and 40 ° N.

Var. *major* is most aggressive and found most in Asia. It has smaller spikelets than others and has hairy nodes while most others do not have.

Problem. Cogongrass causes a big problem in plantation crops, e.g., rubber, oil palm (Malaysia), tea (Ceylon, India, Indonesia), coconut (Ceylon, Malaysia) (11). It is also a great problem in newly reforested plantation. In Thailand the problem can also be found in fruit trees as well as in perennial crops like pineapple and sugarcane. Annual upland rice are not much subject to the problem due to the land is tilled every 3 to 4 months for soil preparation, and normally the soil is left sun-dried more than a week and then retilled. By doing this way a lot of rhizomes are killed every time. Upland rice is usually infested with the grass due to the land preparation is not well processed. Even worst, sometimes farmers never do at all, because they grow by no-tillage method. Another reason is due to most upland rice fields are in or near the forest and usually surrounded by the grass as patches or as a sheet. The situation is the same with plantation crops. Normally the areas for newly planted plantations are close to the forests which are full of cogongrass. On the other hand sometimes crops are grown in the area once dominated by the grass. Certainly, it is not completely eliminated, and the problem is inevitable.

Like purple nutsedge, cogongrass multiplies rapidly both sexual and asexual means. Iven (13) estimated the number of florets per inflorescence to range from 500 to 1,000 and in a moderate infestation, there could be 10 to 20 infloresences per square meter. Plume seeds can be carried by wind and other factors even flowing water.

Santiago (28) reported 95% germination within one week of harvest and the seeds viable for at least one year. Rhizomes developed after 4 wk of germination and plant grew fast after that. It fully dominated over the area of 4 m^2 in 11 wk (7). We can find net of rhizomes in underground, mostly 15 to 20 cm deep. The section sized 2 to 5 mm diam even at 1 to 5 cm can germinate to be a new plant. Not all rhizome nodes have buds. Only are near the terminal can germinate.

Cogongrass is tolerant of drought. Burning, cutting, and grazing can lower the rhizome weight, not killed, but enhance flowering (31). It can tolerate water logging on heavy soil (11). To my own observation, even for 3 months in soil under water level, not all of, the weed were killed.

The weed generally recognized to be a light-loving plant which can be "shaded out" under a heavy canopy. Though it is weakened it remains ready to invade areas which open up as a result of disease or ant reason. Soerjani (31) found that even 50% shade did not eradicate the weed.

Cogongrass can thrive in a wide range of soils from the poor to highly fertile ones. However, it becomes established most quickly on medium to good soils and is less frequently a pest.

Competition. Cogongrass is very competitive and the growers have realized this for a long time. Experiments in rubber plantations in Malaysia show that, for the first 5 years after being planted, trees surrounded by the grass made about 50% of the annual growth of trees which were free from the weed or which had a legume ground cover of *Centrosema pubescens* (2).

In immature rubber, Yeoh and Pushparajah (41) found that one year after the control of *I. cylindrica* by dalapon and glyphosate, the growth increment in untreated plots was 18% significantly less than the treated plots. Forest trees can be suffered from the weed. Coster (7) reported that the growth of teak trees, *Tectona grandis*, in the first year was 13 cm in plots of *I. cylindrica* and 100 cm in plots where the weed had been removed.

Management. Actually before planting farmers should make sure that they do not have the grass in the areas. So, eradication is necessary as well as prevention (see in conclusion). In case it has spread already, steps of control must be taken.

Tillage method is till used where the situation permits and you feel that it is more feasible. Cross cultivation with a tractor (deep enough) to turn up the rhizomes to expose to the sun 3 times at weekly interval in dry season gave 90% control of the weed (24). The first ploughing should be after the last rain while soil still soft. Kasasian (15) also reported that the weed can be eradicated by regular cultivations (every 3 to 4 weeks). The fragment with less node numbers (short rhizome pieces) germinated less compared with the more nodes (longer piece). The method can be combined with others.

Slashing is still practiced by some fruit growers. Actually, they do not allow the weed close to the bases of crops or canopy edges. The slashed leaves are collected and thrown under the tree canopy to preserve moisture. And it works in that situation which drought is so severe in dry season. I think possibly there could be other plants better than the grass, e.g., *Vetiveria zizanioides*, but research is needed.

For habitat management, one should know that cogongrass is sensitive to other weeds as mentioned earlier. *R. cochinchinensis* was reported be grown to suppress cogongrass (3). In another case even now people still grow a small and climbing grass, *Microstogium oiliatum* (Trin.) A. Camus, to suppress this weed (27) and also other weeds in mangosteen plantation. In Thailand people have used sesame (*Sesamum indicum* L.) for control of the grass for a long time. Strangely enough it works. Premasthira and Zungsontiporn (23) also grew 2 sesame plants in association with 2, 3, and 4 cogongrass plants in the container 490 cm^2 with soil and they found that dry weight of the grass was reduced more than 50% and tillering reduced 21 to 44%.

Inter-cropping and growing cover crops are common practiced in rubber or oil palm due to the row space for these crops is wide (7 to 8 m), if not it will be occupied by weeds Legume cover crops used mostly are *Calopogunium mucunoides*, *Pueraria phaseoloides*, and *Centrosema pubescens*. All these are planted in mixture at the ratio 2:2:3 at 7 kg/ha, or only the last two species can be used at 2:30. Lately another one which is very good, *C. caeruleum*, can be added at 350 g/ha.

Chemicals are necessary for control of the grass. Long time ago dalapon was the only one which effective. Now, glyphosate (also sulfonate) is quite practical and practically without soil residue. Optimum rate depends on location (possibly biotypes ?). In Thailand the rate 1.92 to 2.25 kg ae in 625 L/ha is enough (4) but in Malaysia (16) and Indonesia (36) they use 2.16 to 4.32 kg ae in 550 L/ha. High spray volume causes problem in finding the water, esp. on the hilly areas. Lately a lot of modifications have been created to use less volume. Mist blower can also be used practically at 30 L/ha (C. Boonarirat, 1995. Personal communication). However, a good quality surfactant with enough amount is required.

Imazapyr is another compound which is very effective on *I. cylindrica*. Optimum rate is 0.5 to 1.0 kg ae/ha (5). Due to its residual activity the chemical is not much as popular. However, rubber trees aged ranging 9 months to 4 years was found selective at 0.375 to 1 kg ae/ha. Also, 2 years old plant showed tolerance to 6 applications of the chemical 0.75 to 1.5 kg ae made at 90 day interval (5). Certain forest species, i.e., *Acacia mangium*, *Schima wallichii*, *Eucalyptus deglupta*, and *Swietenia macrophylla*, were found to grow better in the imazapyr treatment compared with that in the other treatments, because of the improved efficiency by imazapyr on cogongrass (32). Imazapyr was applied 1 month preplant. For growing cover crops, one month delay after cogongrass application with imazapyr was found enough. The advantage are that the treated plants were slowly decomposed, and the area was not found much of germinating weeds (C. Boonsrirat, 1995. Unpublished). The chemical did not show deleterious effect on rice either when applied 1 month or more before sowing seeds (8).

However, other than herbicide efficiency and selectivity, the cost should be considered too. Usually farmers integrate physical and chemical methods, or chemical and habitat management together, e.g., herbicide application preceded by burning or slashing (herbicides applied to new regrowth), or growing legume covers after herbicide application.

Uses. The most usefulness of *I. cylindrica* is thatching for houses, which a number of villagers still use it. The grass in vast area can be a standby forage crop for the cattle, but only the very young plants after burning. Its leaves can also be used as mulching material for vegetable growing, especially when grown by seedling. If can also be used as soil binder to prevent erosion (11). For medicinal purpose, the grass rhizomes can be used as diuretic treatment (22).

Conclusion

Established infestation of noxious weeds is very difficult to control, so taking the preventive measures is the better thing. Do scouting the field regularly and get rid it of the weed when spotted every time. Escape weeds must be eradicated with no choice. Consider using cover crops both in cultivated and non-cultivated areas. *Dolichose lablab* is a good one and young pods can be eaten as a food.

Reference

1. Ahmed, Ali Ibrahim. 1993. Some biological aspects of purple nutsedge (*Cyoerus rotundus*), its competition, and control in corn (*Zea mays*). Ph.D. dissertation, Dept. of Horticulture, Kasetsart Univ., Bangkok. 104 p.

2. Anonymous. 1938. The effect of lalang on the growth of young rubber trees. Jour. Rubber Research Inst., Malaysia 8: 227-231.

3. Bamrungwate, N. 1981. Pongkhai, a weed or cover crop. Kasikorn 54(7): 29-34. (InThai)

4. Boonsrirat, C., A. Chantuma, and S. Sukmark. 1982. Herbicide application in rubber (*Hevea brasiliensis*) planting. Thai Jour. of Weed Science. 1(1): 3-22.

5. Boonsrirat, C., K. S. Chee, and S. C. Lee. 1985. AC 252,925: A new herbicide for use in rubber plantations. Proc. Asain-Pacific Weed Sci. Conf. 10(1): 99-106.

6. Cardenas, J., C. E. Reyes, J. D.Doll, and F. Pardo. 1972. Tropical Weeds. Centre Regional de Ayuda Technica, Mexico/ Buenos Aires. 341p.

7. Ester, C. 1932. Some observations on the growth and control of *Imperata cylindrica*. Tectona . 25: 383-402.

8. Cox, T. I. and D. E. Johnson. 1990. Review of research progress in *Imperata cylindrica* control techniques for small-holder farmers. Proc. Tropical Weed Sci. Conf. 31: 257-265.

9. Faijaroenmongkol, W. 1995. Application of glyphosate in combination with imidazolinones or chlorimuron for control of purple nutsedge (*Cyperus rotundus*) in soybean (*Glycine max*). Master thesis. Kasetsart Univ., Bangkok

10. Guantes, M. M. 1974. Competitive effects of *Cyperus rotundus* L., *Echinochloa colonum* (L.) Link and *Trianthema portulacastrum* L. on cooton. M.S. thesis. Univ. of Philippines at Los Banos.

11. Holm, L.G. D. L. Plucknett, J. V. Pancho, and J. P. Herberger. 1977. The World's Worst Weeds. Distribution and Biology. The University of Hawaii Press. Honolulu. 609 p.

12.Hubbard, C., D. Brown, A. Gray, and K. Whyte. 1944. *Imperata cylindrica*, taxonomy, distribution, economic significance and control. Imperial Agricultural Bureau Joint Publication 7. Imperial Bereau of Pastures and ForageCrops. Aberystwyth, Cardiganshire. 63 p.

13. Ivens, G. W. 1975. Studies on *Imperata cylindrica* (L.) Beauv. and *Eupaterium odoratum* L. Technical Report. Agricultural Research Council, Weed Research Organization No. 57, 277 p.

14. Jantawinyurag, R. 1995. Study on biology and control of itchgrass (*Rottboellia cochinchinensis*) and its effect on growth and yield of soybean. Ph D. dissertation. Dept. of Agronomy, Kasetart Univ., Bangkok. 250 pp.

15. Kasasian, L. 1971. Weed Control in the Tropics. Leonard Hill, London. p. 77.

16. Lee, S. A. 1985. The control of *Imperata cylindrica* (L.) Beauv. by glyphosate, sulfosate, and AC 252925. Proc. Asian Pacific Weed Sci. Conf. 10(2): 635-644.

17. Lejeune, K. R., J. L. Griffin. D. B. Reynolds, and A. M. Saxton. 1994. Itchgrass (*Rottboellia cochinchinensis*) interference in soybean (*Glycine max*). Weed Technol. 8(4): 733-737.

18. Meister Publishing Company. 1994. Weed Control Manual. Willoughby, Ohio. 362 p.

19. Mercado, B. L. 1978. Biology, problems and control of *Rottboellia exaltata* L. f. BIOTROP Bull. No. 14. 38 p.

20. Mercado, B. L. 1979. Introduction to Weed Science. Southeast Asian Regional Center for Graduate Study and

Research in Agriculture, SEARGA, College, Laguna, Philippines. 292 p.
21. Mercado, B. L. 1979. A Monograph on *Cyperus rotundus* L. BIOTROP Bull. No. 15. 63 p.
22. Muanwongyat, P. 1985. The use of weeds for medicinal purpose. Thai Journal of Weed Sci. 3(142): 85-98.
23. Premasthira, C. and S. Zungsonthiporn. 1993. Competition of sesame (*Sesemum indicum*) population with cogongrass (*Imperata cylindrica*) Annual Report 1993. Weed Science Branch, Division of Botany and Weed Science. Department of Agriculture. p. 37-46.
24.Prompuak, B. 1955. The new method in controlling lalang. Kasikorn 28(2): 200-201. (In Thai)
25. Rao, J. S. and N. Nagamjan. 1963. Relationship between moisture levels and viability of nutgrass tubers. Madras Agric. J. 50(3): 120-123.
26. Richards, P. V. M. and P. E. L. Thomas. 1970. An approach to the control of *Rottboellia exaltata* in maize. Proc. 10th British Weed Control Conf. 689-696.
27. Saiyupratham, T. 1959. *Pollinia ciliata*, the lalang suppressor. Kasikorn 29(9): 154-156 (In Thai)
28. Santiago, A. 1965. Studies on the autoecology of *I. cylindrica* (L.) Beauv. Pages 499-502 in Ninth International Grassland Congress, Sao Paulo.
29. SEAWIC. 1991. *Rottboellia cochinchinenesis* (Lour.) W. D. Clayton. Weed Info. Sheet 9 December. SEAMEO. BIOTROP 2p.
30. SEAWIC. 1992. *Cyperus rotundus* L. Weed Info. Sheets 15 December. SEAMEO BIOTROP 2p.
31. Soerjani, M. 1970. Alang-alang, *Imperata cylindrica* (L.) Beauv. Pattern of growth as related to its problem of control. BIOTROP Bull 1. 8 p.
32. Subagyo, T., T. Iomail, E. Iswahyudi, and Bustomi. 1990. Chemical control of alang-alng, *Imperata cylindrica* (L.) Raeuschel for land preplantation before forestation. Proc. Tropical Weed Sci. Conf. 3: 249-256.
33. Sukwiriyasatira, W. 1995. Competition and control of itchgrass (*Rottboellia cochinchinenesis*) by certain herbicides integrated with tillage system in corn. Master thesis, Dept. of Agronomy. Kasetsart Univ., Bangkok. 58 p.
34. Suwunnamek, U., S. Thongma, and W. Sukwiriyasatira. 1990. Itchgrass (*Rottboellia cochinchinensis*)control with herbicides (summary). Twenty second National Corn and Sorghum Reporting Session, 13 to 17 May 1990, ChaingMai.
35. Thongma, S. and U. Suwunnamek. 1988. Successively integrated control of *Cyperus rotundus* in one year round. Proc. Tropical Weed Science Conf. 2(1): 34-44.
36. Thongmee-arkom, P., S. T. Chew, and A. Arif. 1985. Effective *Imperata cylindrica* (L.) Beauv. Control with reduced rates of glyphosate and management practices. Proc. Asian-Pacific Weed Sci. Conf. 10(1): 245-248.
37. Ueki, K. 1969. Studies on the control of nutsedge (*Cyperus rotundus* L.) on the germination of a tuber. Proc. Soc. Asian-Pacific Weed Control Interchange (Cited in A Monograph on *Cyperus rotundus* L. by B. L. Mercado 1979. BIOTROP Bull. 15)
38. Weed Science Society of America. 1989. Herbicide Handbook, Sixth Edition. Published by Weed Sci. Soc. of America, Champaign. Illinois. 301 p.
39. Westmoreland, W. G., G. C. Klingman, and R. P. Upchurch. 1955. Nutgrass (nutsedge) control. (C. F. Horticultual Abstract 25: 421, 1955.)
40. William, R. and G. F. Warren. 1974. Competition between purple nutsedge and vegetables. Weed Sci. 23: 317-323.
41. Yeoh, C. H. and E. Pushparajah. 1976. The control of *Imperata cylindrica* (lalana) in Malaysia. Proc. Rubber Res. Inst. Malaysia Planters Conf., Kuala Lumpur, p. 250-273.

THE SUCCESSION OF NOXIOUS WEEDS IN TROPICAL ASIAN RICE FIELDS WITH EMPHASIS ON MALAYSIAN RICE ECOSYSTEMS.

Azmi, M.* and B.B. Baki
*MARDI Rice Research Centre, 13200, Kepala Batas, Seberang Prai, Malaysia,
and Botany Dept., University of Malaya, 59100 Kuala Lumpur, Malaysia.

Abstract: Both allogenic and autogenic successions occurred among weed communities in tropical Asian rice ecosystems. These successions were largely attributed to changes in habitat brought about by and in response to changes in crop establishment techniques, weed management and other agronomic practices of what used to be low pesticides and low fertilizer sedentary traditional farmings to pesticides and inorganic fertilizer-oriented, irrigated and mechanised rice farmings. The consequential changes in weed community populations and species diversity was brought about principally by the shift in rice culture replacing the labour intensive transplanting technique with direct-seeding alternative since the mid-1980's. Direct-seeded rice culture and continuous use of phenoxy herbicides then have resulted in species shift in weed community structure favouring the more competitive graminoids, viz. *Echinochloa crus-galli* complex, *E. colona, Leptochloa chinensis, Ischaemum rugosum* and *Paspalum distichum* in tropical Asia and of late, weedy rices *(Oryza sativa)* in Malaysia. Being C_4 plants, these graminoids are well adapted to hot, arid and high intensity light regimes prevailing in the tropics. These species are also comparatively efficient in nitrogen and water uptake and can inflict severe yield losses on rice. The predominance of graminoids in direct-seeded rice culture since mid-1980's, has led to inevitable changes in the pattern of herbicide use favouring the highly selective graminicides among farmers. This in turn favoured the proliferation and recurrence of broadleaved weeds and sedges at the expense of graminoids.

Keywords: allogenic, autogenic, successions, weed community, species diversity, weed management, agronomic practices, phenoxy herbicides, graminicides, *Echinochloa crus-galli, E. colona, Leptochloa chinensis, Ischaemum rugosum, Oryza sativa, Paspalum distichum*

INTRODUCTION

Rice is a major food crop in the tropics. The recent emphasis on direct seeded rice culture in the tropics especially in Asian countries is due to widespread use of herbicide in controlling weeds (De Datta & Flinn, 1986) and rising labour cost in the Philippines, Thailand and Malaysia (Ho, 1991).

In the past decade in Southeast Asia, there has been a shift in the rice production system from transplanting to direct seeding (DSR), of which wet seeding (pre-germinated seeds broadcast on puddled soil) has been the main method of rice culture in Malaysia, Thailand, Philippines, Vietnam and Sri Lanka (Moody, 1993). Meanwhile, dry seeding of rice onto non-puddled soils is practised in India, Bangladesh, Indonesia and parts of Sri Lanka (Upasena, 1980 cited in Moody, 1983).

In irrigated rice areas of Thailand, the Philippines, Sri Lanka, Malaysia, Fiji Island and Vietnam, rapid changes from transplanting to direct-seeded method have been motivated *inter-alia* by the introduction of effective herbicides, development of short-culm and early maturing rice cultivars and burgeoning labour cost of transplanting (Itoh, 1991). Currently more than 90% of the irrigated rice area in Peninsular Malaysia is now direct seeded instead of the traditional transplanting.

Weed populations in areas free from disturbance by tillage regimes or herbicides are considered to be relatively stable, in terms of density and species diversity (Harper, 1977). However, when ecosystems are disturbed or cultivated as in most agricultural situations, weed populations change, colonizing bare ground, a response typical of ruderal species (Groves, 1992).

It is the opinion of Connell & Slatyer (1977), *inter-alia,* that contemporary ecological thinking has shifted from the early Clementsian idea of a successional series of species moving towards inexorably towards a stable state (the *climax climatic*) incorporating at least three possible pathways. Due to the continuous nature of disturbance by cultivation, tillage operations, herbicide application, and other agronomic practices, the appropriate model of succession for a weedy agricultural land lies 'somewhere' between the *tolerence model* applying to secondary succession and the one Connell and Slatyer (1977) denoted as *inhibition model*. The former model in the absence of further disturbance depicts an old-field succession. Invariably, the net effect of agricultural operations is to maintain vegetation at an early successional stage suitably adapted for competitive ruderals.

The weed flora in a rice field is greatly influenced by the method of rice culture (Ampang-Nyarko & De Datta, 1991). Continuous rice cultivation with unchanged cultural system encourages the buildup of weeds adapted to that system. Although weed problems in rice vary from one ecosystem to another, it is widely accepted that weeds cause more damage than other pests and this is more severe in upland rice than in all other ecosystems in which rice is grown (Akobundu, 1987).

NOXIOUS WEEDS IN RICE

Noxiousness is a measure of both the undesirability of a weed and the difficulties in controlling it (Akobundu, 1987). There are about 350 weed species in 150 genera with 60 families known to be problematic in rice (Smith, 1983). Of these, species of Poaceae are the most common with more than 80 species. Among them are *E. crus-galli, L. chinensis, I. rugosum, E. colona* and weedy rice (*Oryza sativa/O. spontanea*).

In tropical Asian countries, the moderately warm to high temperature and high humidity favour year-round luxuriant weed growth. Among them are *Echinochloa crus-galli* complex, *E. colona, E. oryzicola, Leptochloa chinensis* and *I. rugosum* (Itoh, 1991; Ho, 1991). These weeds have become dominant and competitive in DSR in the tropics.

The advent of direct seeding and the continuous usage of phenoxy-group of herbicides and inadequate water supply, *inter-alia* are factors perceived to be responsible for the shift in weed species dominance and diversity in rice ecosystem. *Echinochloa crus-galli* complex(*E. crus-galli* var, *crus-galli, E. crus-galli* var. *formosensis*), along with other *Echinochloa* aggregates (*E. oryzicola, E. colona, E. stagnina* and *E. picta*), *Leptochloa chinensis, Ischaemum rugosum* and *Paspalum distichum*, which were not so prevalent and dominant Malaysian rice fields in the 1970's (Baki and Azmi, 1992; Azmi *et al.*, 1993) became widespread in the 1990's. In many areas of the Philippines, *E. crus-galli* are fairly common in wet-seeded rice (Casimero *et al.*, 1994). Other weeds reported to be of importance were *P. distichum, I. rugosum, M. vaginalis* and *Sphenoclea zeylanica*.

Echinochloa crus-galli, a cosmopolitan and noxious species in many tropical crops, is regarded as the principal weed of rice (Holm *et al.*, 1977). It has been reported as a weed in 61 countries and 36 different crops (Barret, 1983). The world distribution of *E. crus-galli* ranges from 50°N to 40°S latitude (Figure 1) (Holm *et al.*, 1986). The ecological requirements of *E. crus-galli* are very similar to rice and certain varieties of the former are very difficult to distinguish from one another in the early stages of growth (Yabuno, 1966). Barnyardgrass is a C_4 plant and grew very well under wet condition (Maun & Barret, 1986). In addition, C_4 weeds have higher net photosynthetic rates, water and N use efficiency than do the C_3-plants of which rice is one under all light regimes (Ampong-Nyako & De Datta, 1989). Under shade, therefore, C_4 weeds have a competitive advantage over rice.

Echinochloa crus-galli complex has three subspecies namely *E. crus-galli* var. *crus-galli, E. crus-galli* var. *formosensis* and *E. crus-galli* var. *praticola* (Kim, 1994). Both *E. crus-galli* complex and *E. oryzicola* resemble the rice plant and their growth is restricted to rice fields. These species are important weeds in South east and east Asia.

In case of *L. chinensis*, a true indigene of tropical Asia (Soerjani, 1987), is a common weed of rice in Malaysia, Indonesia, Pakistan, Sri Lanka, Burma, Thailand, Laos, Cambodia and Vietnam. In the Muda area, Malaysia, *L. chinensis* is rated as one of the most noxious weeds in DSR (Itoh, 1991). Like *E. crus-galli*, it is a C_4 species and is highly adapted to hot, arid and high light conditions (Ampang-Nyarko & De Datta, 1991). In growth strategy, the weed is positioned closer to the *r* end of the *r - K* continuum (Radosevich & Holt, 1984). Extreme *r*-selection leads to a short-lived plant (usually less than one year), occupying open habitats and early stage of succession. A large proportion of biomass of *r*-strategists is allocated to reproduction and the population is regulated by physical factors.

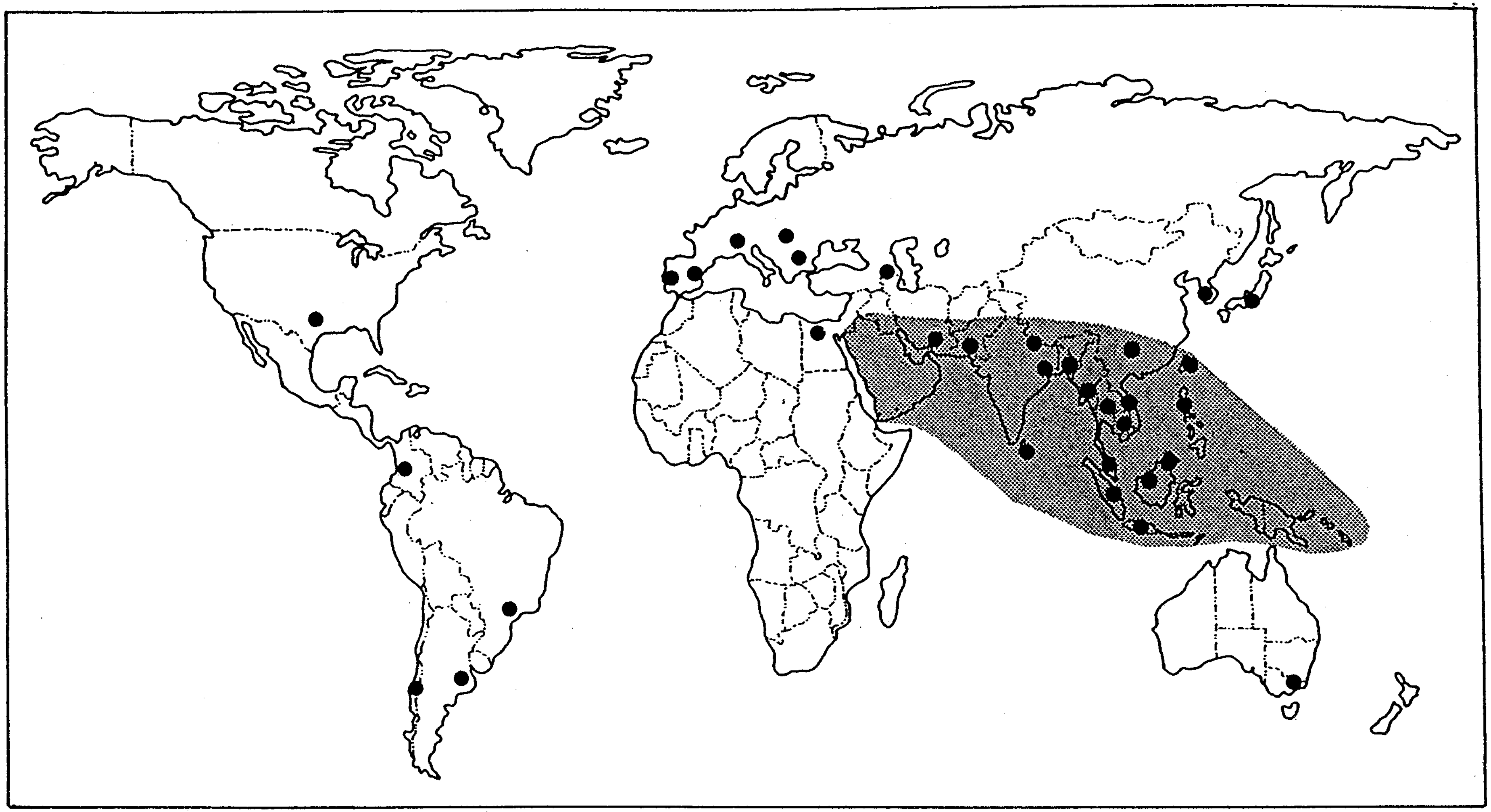


Figure 1. *Echinochloa crus-galli* (L.) Beauv. across the world and in tropical Asian region where it has been reported as a weed in rice (adapted from Holm *et al.*, 1977)

Another important grass weed in tropical rice areas is *Ischaemum rugosum*. It was reported to be major weed of partially irrigated and rainfed lowland rice in Thailand, Sri Lanka, Philippines, Malaysia and India (Lubigan & Moody, 1989, Holm *et al.*, 1977; Azmi *et al.*, 1993). It is an annual grass and a native of tropical Asia (Holm *et al.*, 1977). It is easily recognized by its spiral awns and by the prominent transverse ridges on the lower glume of the spikelet.

Echinochloa colona is also an important weed species in rice in Philippines and India (Holm *et al.*, 1977). It is an annual grass and a native of India. The weed is an excellent competitor and if rice crop is badly managed the crop may be forced out by this weedy plant. It has prostate growth habit in early seedling stages.

An emerging threat in DSR in tropical Asia is weedy rice. Weedy rice can be defined as rice plants which occur spontaneously as weeds within or around rice fields (Moody, 1994). Moody (1994) reported weedy forms of rice occurred in Malaysia, Philippines and Vietnam. In Malaysia, weedy rice is locally known as *padi angin. Padi angin*, with many morphological variants, has high degree of deciduousness before being harvested (Wahab and Suhaimi, 1990). Baki (unpublished) recognized at least 80 variants of weedy rice species in Malaysia. Many theories have been put forward on origin of weedy rice. Moody (1994) lists 6 possible ways in which weedy rice can evolve, *viz;* (a) outcrossing with wild or shattering rice, (b) segregants of a heterogeneous cultivar, (c) degeneration of the cultivar due to continuous use, (d) seed mixtures, (e) volunteers from the previous crop and (f) mutation. Similar arguments have been forwarded by Abdullah *et al.* (1994).

The seeds of noxious weeds often enter rice fields with crop seeds (Holm *et al.*, 1977). They may be transferred from neighbouring fields through farm machineries and on the feet, fur, feathers and skin of rodents, birds and larger animals including human.

Weed succession and distribution patterns in rice fields are dynamic in nature and are governed by spatio- temporal elements, and the agronomic practices being employed. As such species dominance and their patterns of distribution varied considerably. A few species, could claim the status of ubiquity in rice areas of Peninsular Malaysia in 1980, i.e. *Monochoria vaginalis, Ludwigia adscandens, Fimbristylis miliacea, Scirpus grossus, Limnocharis flava, Leersia hexandra, Cyperus haspans* and *L. hyssopifolia* (Baki & Md. Khir, 1983).With the widespread of direct-seeding in the 1990's, there is a dramatic shift in weed flora in the rice fields. Azmi *et al.* (1993), reported *E. crus-galli* was the most dominance weed in DSR. Other important weeds in rice included *F. miliacea, Limnocharis flava* and *M. vaginalis.* Comparison of shift in weed dominance after about 10 years in Malaysian rice fields is shown in Tables 1 and 2.

Ho (1991) recorded meaningful shift in species dominance among rice weeds in the Muda granary, arguably brought about by the change in rice culture from the dominantly transplanting rice culture in 1979 to direct-seeding in 1989 (Table 3). Rapid rise of *E.crus-galli* as the most dominant weed species in DSR in Kemubu rice area, Malaysia was found to be related to the adoption of DSR Azmi (1994). In 1989 season only transplanted rice was adopted in the granary. However, 50.4% of the area involved with DSR in 1991 season and 79.6% of DSR in 1993 season. Table 4 enlists major weeds of rice in Southeast Asia, (Waterhouse, 1991).

FACTORS INFLUENCING WEED SUCCESSION IN RICE ECOSYSTEM

(a) Crop establishment technique

In a review on changes in weed flora associated with reduced tillage systems, Froud-Williams *et al.* (1981) cited several studies where perennial monocot and dicot species increased in the absence of tillage. They were of the opinion that perennial monocots constituted the greatest threats to adoption of reduced tillage systems. Further, reduced tillage would favour rhizome and stolon-bearing perennials over annuals. Similar findings of more diverse populations of perennials weeds developed in reduced tillage regimes (Buhler *et al.*, 1994). The work of Pollard & Cussans (1976) noted the high prevalence of perennials in non-tillage compared to systems that included preplant tillage. Impact studies of agronomic practices on weed communities by Derksen *et al.*, (1993, 1994) revealed no increase in association of perennial and annual grasses with zero tillage. They also observed that changes in weed communities were greatly influenced by time and space rather than tillage systems operating, indicating

Table 1. Comparison of ranking of 15 species dominance of major-rice field weeds in Peninsular Malaysia in 1980 and 1990 based on importance value indices

Weed species	Ranking	
	1983[a]	1993[b]
Monochoria vaginalis	1	4
Fimbristylis miliacea	2	2
Ludwigia repens	3	-
Leersia hexandra	4	-
Cyperus haspan	5	-
Limnocharis flava	6	3
Scirpus grossus	7	13
Eleocharis variegata	8	-
Ludwigia hyssopifolia	9	6
Salvinia molesta	10	-
Scirpus juncoides	11	-
Isahne globosa	12	-
Utricularia aurea	13	12
Scirpus mucronatus	14	-
Lindernia pedunculata	15	-
Echinochloa crus-galli	-	1
Echinochloa colona	-	7
Leptochloa chinensis	-	5
Sphenoclea zeylanica	-	14
Marsilea crenata	-	10
Cyperus iria	-	8
Cyperus difformis	-	15
Najas graminea	-	11
Sagittaria guyanensis	-	9

- minor weeds
[a] Baki & Md. Khir (1983)
[b] Azmi, *et al.* (1993)

Table 2. Weed shift from transplanting to direct seeding method in Peninsular Malaysia

Irrigated transplanting (1970's)	Extensive direct seeding (1980's- 1990's)	Intensive direct seeding in future
Grasses		
Isachne globosa	*Echinochloa crus-galli*	*L. chinensis*
Leersia hexandra	*Leptochloa chinensis*	*E. oryzicola*
	O. sativa (weedy rice)	*O. sativa* (weedy rice/volunteer seedlings)
Broadleaved weeds		
Limnocharis flava	*L. flava*	*S. guyanensis**
Monochoria vaginalis	*M. vaginalis*	*M. vaginalis***
	Sagittaria guyanensis	*Spenoclea zeylanica***
Sedges		
Scirpus grossus	*Cyperus iria*	*F. miliacea***
		*C. iria***

* Herbicide resistant species (2,4-D)
** Herbicide resistant biotypes (2,4-D)

Table 3: Changes of weed flora and dominance from transplanting to direct seeding in the Muda area (1979 - 1989) modified from (Ho, 1991)

Diversity indicator & % direct-seeded area	Season					
	2/79	1/82	1/84	2/84	1/87	1/89
No. of species	21	34	42	45	50	57
No. of genera	18	18	30	30	38	44
No. of families	13	14	19	17	22	28
% direct seeded area	0.2	20.7	53.0	24.0	98.9	81.7
Dominant weed species*	M.vag	M.vag	F.mil	E.cru	E.cru	E.cru
	L.hys	L.hys	M.vag	S.gro	E.col	L.chi
	F.mil	F.mil	E.cru	L.hys	L.chi	F.mil
	C.dif	L.hex	S.gro	P.amp	S.gro	M.cre
	L.fla	S.gro	M.cre	L.chi	F.mil	M.vag

*M.vag - *Monochoria vaginalis;* S.gro - *Scirpus grossus;* L.hys - *Ludwigia hyssopifolia;* E.cru - *Echinochloa crus-galli;* F.mil - *Fimbristylis miliacea;* M.cre - *Marsilea crenata;* C.dif - *Cyperus difformis;* P.amp - *Panicum amplexicaule;* L.fla - *Limnocharis flava;* L.chi - *Leptochloa chinensis;* L.hex - *Leersia hexandra;* E.col - *Echinochloa colona*

Table 4. The distribution and importance of the most important rice weeds in Southeast Asia (modified from Waterhouse, 1993)

Scientific Name	MYAN	THAI	LAOS	CAMB	VIET	MSIA	SING	BRUN	INDO	PHIL
Aeschynomene indica	•	+	•	++	•	•			•	++
Alternanthera sessilis	+	+	•	•	+	+	++		•	++
Borreria latifolia		•				+++	++		++	+
Brachlaria mutica		•	•		•	++	+		+	
Cleome viscosa	+	•		•	•	+	++		•	
Commelina benghalensis	++	+++			+	•			++	++
Commelina diffusa	•	++	•		•	•	++		++	++
Cynodon dactylon	++	++	+	+	+++	++	++		+++	++
Cyperus brevifolius	•	•	•	•	•	+	+			++
Cyperus compactus						+	+		•	++
Cyperus compressus	+	+	•	•	•	++	++	+	+	++
Cyperus difformis	+	+	+	++	+++	+++	+		++	+++
Cyperus iria	++	++	++	++	+++	+++	+		•	++
Cyperus kyllingia		•	•	•	++	++	+++	•	+++	++
Cyperus rotundus	+++	+++	++	++	+++	++			•	+++
Digitaria sanguinalis					•					+++
Digitaria violescens	•	•	•	•			++	++	•	++
Echinochloa crusgalli	•	+++	+	++	+++	+++	++		+++	+++
Echinochloa glabrescens		•	•	++	+++	+++		+	+++	+++
Echinochloa oryzoides	•	•			•	•			•	++
Eclipta prostrata	+	++	•	•		•	++			+++
Eichhornia crassipes	++	+++	++	++	++	+++	•		+	++
Eleusine indica	++	++	++	++	+	+++	+++	++	++	+++
Fimbristylis dichotoma	++	+	++		•	+	++		+++	+
Fimbristylis globulosa	•	•	•	•	++	++	++		+++	++
Fimbristylis miliacea	+++	+	+	+++	•	++	++		•	•
Hellotropium indicum	+	+	•	•	+	+++	•		+++	++
Hydrilla verticillata	•	++	•	•	•	•	+	•	•	++
Hymenachne actigluma						+	++		+	+

Table 4: (continued)

Ischaemum muticum	+	•	•	•	•	++	++	•		+
Ischaemum rugosum	•	+	+	+	+	+++	+	+	++	++
Leersia hexandra		+	+	+	++	++	+	+	•	+
Leptochloa chinensis	+++					+++			++	++
Limnocharis flava		+	•	•	•	++				
Lindernia crustacea	+				•	++	+	•	•	
Ludwigia adscendens	+++	+	•	•	•	++	++		•	•
Ludwigia hyssopifolia	+	++	•	•	•	++			•	++
Ludwigia octovalvis	+	•	•	•	•	•	•		•	+
Marsilea minuta	•	+	+	+	+	+++	+		+	++
Marsilea quadrifolia	+	•	•	•	+++			++	++	++
Melochia corchorifolia	++	•		•	•	+++			•	+
Mimosa invisa	++	+++	++	+	++	+++	++		•	+
Mimosa pigra	+++	+	•	•	+	++	++	++	++	+++
Mimosa pudica					+	++	+++		++	
Monochoria hastata	++	++	+++	+++	+	++	+	+++	+++	++
Monochoria vaginalis		•			++	•	++	•	+	
Oldenlandia corymbosa	++	+	•	•	•	+++	++		+++	+++
Oryza rufipogon	•	•			•	++			•	+
Paspalum distichum	•	•	•	•	•	+			+	•
Paspalum scrobiculatum		+	+	+	•	•	++		+++	++
Pennisetum prupureum	+	++	++	++	+	++	+	+	•	+
Pistia stratiotes	•	•	•	•	++	+	•		+	+
Rotala indica	+	++	+		++	+			+	++
Rottboellia	•	•	•	•	+	++			•	+
cochinchinensis		++	+	+	•	+	+		+++	+++
Sagittaria guyanensis					+	+++			•	
Salvinia cucullata	++	•	•	•		•	+		•	
Salvinia molesta	++	•	•	•	+	+++			+	++
Scirpus grossus	•	•	•	•	•	+++			•	+
Scirpus juncoides					•	++			+	•
Scirpus maritimus						•			•	+++
Scirpus supinus					•	++				+
Scleria sumatrensis	•	•				++	+			

+++, very widespread and very important; ++, widespread and important; +, important locally; •, present, but not important fluctuational rather than directional or consistent changes in community composition. Sagar (1970) presented schematic representation of factors that may control the size and to a certain extent species succession in an agricultural area.

Weed populations in rice are influenced by crop establishment method. Baki and Azmi (1992) have reported that more broadleaved weeds grow in association with transplanted rice while more grassy weeds with wet seeded rice. Moody and Drost (1981) reported weed problems will be less prevalent when wet seeded or transplanted rice is grown as the first crop than dry-seeded rice. Pablico *et al.* (1994) reported that water seeding changed species composition of the major weeds from grasses and sedges to broadleaved weeds which accounted for 78-91% of the weed flora by weight. Baki (1995) employing canonical discriminant analysis in his extensive studies on the influence of tillage regimes and weeding practices of weed communities in direct-seeded rice in Malaysia reported that spatio-temporal changes in weed community in the rice granary of Seberang Perai, if any, were erratic and fluctuational and were dependent on crop season and influenced by weeding practices and inherent differences in species composition between plots. As pointed by Derksen *et al.* (1994), *inter-alia*, periodic weed assessments in long-term studies which were a point in time samplings, may produce findings which are not truly representative of community response to production practices. While changes in diversity status and species composition in weed communities did occur in Seberang Prai fields among weeded and non-weeded plots, no consistent change in species association has been recorded solely due to tillage regimes. It was obvious that a meaningful changes in weed community both in species diversity and species composition *vis-a-vis* tillage regimes and other agrotechnical practices need a longer period of experimentation and are likely to be dependent upon species, time and environmental variables.

The non-weeded plots registered higher overall densities ranging from 80.9 ± 7.3 to 88.0 ± 6.2 plants/m^2 than the weeded plots with 26.9 ± 6.2 - 30.4 ± 10.6 plants/m^2. These apparent differences in density ratings of weed species between plots subjected to weeding and non-weeding practices were compounded by changes in diversity status and species composition of weed communities in plots subjected to different tillage regimes and time. Marked differences were recorded in the relative density, relative frequency, relative dominance, relative abundance and important value indices between species (Table 5). A total of 29 species of weeds belonging to 14 families were recorded in the 1991-1992 seasons depicting a typical weed flora of rice granary of Seberang Prai (Azmi *et at.* 1992, 1993). Intriguingly, no *Portulaca oleracea* was observed in 1993. Weed communities were dominated by ten species in the order of relative abundance or importance value; *Monocharia vaginalis>Echinochloa crus-galli > Fimbristylis miliacea > Limnocharis flava > Bacopa rotundifolia > Cyperus iria > Sagitaria guyanensis > C. haspans > Paspalum distichum > Rotola rosea.*

It appears that factors other than tillage systems may have contributed to the weed compositional differences. This is exemplified by the significant differences between tillage regimes T_3 and T_4 in 1992 and 1993 but not in 1991 or T_2 and T_4 in 1991 but not in 1992 and 1993. In the Seberang Prai granary of Peninsular Malaysia it is possible that changes in environmental conditions in the field may have contributed to these differences. Infact, 1991 was a relatively drier year compared to 1992 and 1993. Derksen *et al.* (1993,1994) among others, observed that changes in weed communities were influenced more by location and year than by tillage systems, indicating fluctuational rather than directional or consistent changes in community composition. Further, such changes may have been influenced by the relative timing of management practices.

Weed species association and affinity with tillage regime could be assessed for the experimental year when species compositional differences were recorded (Table 5) by comparing vector length and direction. Most of the species present (Table 5) were not particularly associated with a specific tillage regimes, except for ten major species (Figure 2). Differences in association, wherever observed varied with time and to a certain extent, species.

High incidences of *E. crus-galli* populations were associated with plots subjected to minimal tillage regime especially in plots not subjected to hand weeding (Figure 2). These were the case for all seasons of 1991-1993, based on vector lengths. *Echinochloa crus-galli* was a major weed problem in many rice growing countries and Malaysia is no exception (Azmi *et al.* 1993).

The previous argument of increased annual grass species in reduced tillage (Froud-Williams *et al.* 1981) was based on the difficulty in controlling them in cereals especially monocultural crops (Pollard & Cussans, 1976). Similar findings have been shown by Derksen *et al.* (1994) for *Avena fatua* and

Table 5: Weed species recarded at experimental plots in MARDI Research Station, Bertam, Seberang Prai in 1991 - 1993 (Baki, 1995)

No.	Species	Relative density			Relative frequency			Relative dominance			Relative abundance			Importance value		
		1991	1992	1993	1991	1992	1993	1991	1992	1993	1991	1992	1993	1991	1992	1993
1.	*Utricularia aurea* Lour.	0.62	0.55	0.49	0.42	0.33	0.30	0.72	0.64	0.55	0.52	0.44	0.40	1.76	1.52	1.34
2.	*Najas graminea* (non Del) Ridl.	0.45	0.33	0.40	0.53	0.42	0.44	0.52	0.47	0.39	0.49	0.38	0.42	1.23	1.22	1.50
3.	*Lemna minor* L.	4.96	4.36	5.44	5.51	4.98	5.67	5.68	5.82	6.33	5.24	4.67	5.54	16.15	15.16	17.41
4.	*Sagittaria guyanensis* HBK	2.28	1.90	2.31	2.96	3.18	3.40	2.61	2.84	2.32	2.62	2.54	2.86	7.85	7.69	8.03
5.	*Limnocharis flava* (L.) Buchenau	9.24	9.26	9.78	7.75	8.18	8.66	6.96	6.82	6.21	8.50	8.72	9.22	23.95	24.26	24.65
6.	*Spirodela polyrhiza* (L.) Schlaid.	0.32	0.27	0.17	0.28	0.30	0.29	0.42	0.39	0.36	0.30	0.29	0.23	1.02	0.96	0.82
7.	*Rotala rosea* (Poir.) C.D. Cook	3.87	4.72	4.87	3.21	3.74	3.86	3.55	3.50	3.19	3.77	4.23	4.37	10.63	11.96	11.92
8.	*Marsilea crenata* Presl.	1.07	0.98	0.92	1.12	1.48	1.98	1.96	1.88	1.72	1.10	1.23	1.45	4.15	4.34	4.62
9.	*Ludwigia adscendens* (L.) Hara.	0.78	0.68	0.65	1.11	1.08	0.96	1.12	1.06	0.98	0.95	0.88	0.81	3.01	2.82	2.59
10.	*L. hyssopifolia* (G. Don) Exell	2.11	2.08	2.72	3.54	3.42	3.34	2.90	2.88	3.44	2.83	2.75	3.03	8.55	8.38	9.50
11.	*Portulaca oleracea* L.	0.33	0.27	0.00	0.27	0.19	0.00	0.42	0.48	0.00	0.30	0.28	0.00	1.02	0.94	0.00
12.	*Monocharia vaginalis* (Burm. f. Presl.	14.11	14.39	12.06	10.87	9.65	9.77	14.33	14.40	14.34	12.49	12.63	10.92	39.31	38.44	36.17
13.	*Lindernia ciliata* (Colsm.) Pennel	0.27	0.18	0.00	0.37	0.33	0.00	0.42	0.39	0.00	0.32	0.26	0.00	1.06	0.90	0.00
14.	*Bacopa rotundifolia* (Michx.) Wettst.	7.11	6.98	6.92	8.25	8.11	8.62	8.36	8.11	8.37	7.68	7.55	7.77	23.72	23.20	23.91
15.	*Limnophila aromatica* (Lamk.) Marr.	0.44	0.32	0.27	0.53	0.67	0.64	0.62	0.79	0.64	0.49	0.50	0.46	1.59	1.78	1.55
16.	*Sphenoclea zeylanica* Gaertn.	1.38	2.33	2.28	2.46	2.44	2.40	1.72	1.78	1.65	1.92	2.39	2.34	5.56	6.55	6.33
17.	*Echinochloa crus-galli* (L.) Beauv.	12.00	10.72	10.38	7.87	7.08	7.24	10.37	9.24	9.81	9.94	8.90	8.81	30.24	27.04	27.43
18.	*E. colona* (L.) Link.	1.00	1.18	1.31	2.10	3.15	3.37	2.48	3.32	3.58	1.55	2.17	2.34	5.58	7.65	8.26
19.	*Hymenochne acutigluma* (Stend.) Gilliane	1.62	1.58	1.47	1.87	1.92	1.89	2.08	2.02	2.96	1.75	1.75	1.68	5.57	5.52	6.32
20.	*Leptochloa chinensis* (L.) Nees	1.89	1.90	1.74	1.55	1.62	1.60	1.98	2.00	1.89	1.72	1.76	1.67	5.42	5.52	5.23
21.	*Paspalum distichum* Swartz.	2.97	2.82	2.45	5.28	5.32	5.92	4.42	4.59	4.11	4.13	4.07	4.19	12.67	12.73	12.48
22.	*Panicum repens* L.	1.12	1.32	1.48	2.57	2.72	2.61	2.11	2.48	2.51	1.85	2.02	2.05	5.80	6.52	7.60
23.	*Cyperus haspans* L.	4.28	5.92	6.88	4.90	4.94	4.42	2.96	2.87	2.74	4.59	5.43	5.65	12.14	13.73	14.04
24.	*C. babakan* Stend.	2.01	1.49	2.33	2.33	2.11	2.28	2.23	2.42	2.43	2.17	1.80	2.31	6.57	6.02	7.04
25.	*C. difformis* L.	2.18	4.15	4.10	3.76	3.58	3.59	2.42	2.13	1.89	2.97	3.87	3.85	8.36	9.86	9.58
26.	*C. iria* L.	7.66	6.66	6.24	6.29	6.12	5.82	8.06	8.47	8.29	6.98	6.39	6.03	22.01	21.25	20.35
27.	*Fimbristylis miliacea* (L.) Vahl.	8.68	8.22	8.25	5.98	5.75	5.41	4.00	3.62	3.47	7.33	6.99	6.83	18.66	17.59	17.13
28.	*Scirpus gross* L. f.	1.57	2.47	2.44	3.34	3.01	2.82	2.41	2.63	2.80	2.46	2.74	2.63	7.32	8.11	8.06
29.	*S. juncoides* Roxb.	1.04	1.97	1.83	2.98	2.70	2.73	2.17	1.96	1.93	2.01	2.34	2.28	6.19	6.63	6.49

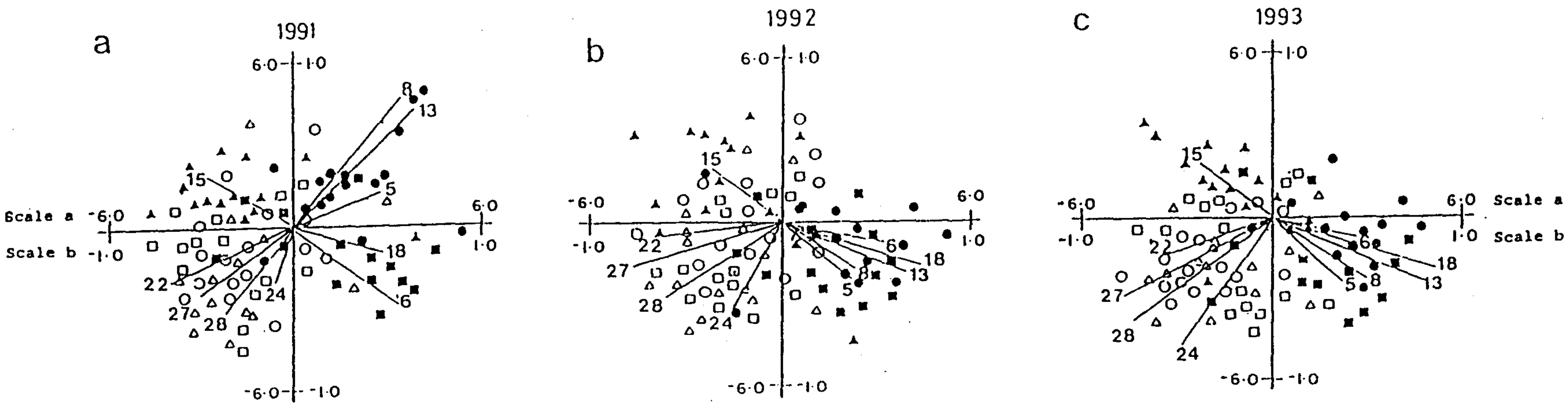


Figure 2: Canonical discriminant analysis ordination diagram of treatment clusters of for zero tillage (●), minimal tillage (■), two rounds (△), three rounds (▲), four rounds (○) and five rounds of conventional tillage (□) regimes (scale a) and biplot scaling of dominant weed species vectors indicating treatment associations at Bertam in 1991-1993 in plots where no hand weeding was done at 15-30 DAS. Symbols represent individual treatment plots abd their position is located based on relative species composition. Species association with treatment can be asscertained by the direction of the vectors. Vector length indicates the relative strength of association between weed species and the respective tillage regime. Vectors labeled for dominant species which have attributed to community discrimination and species idenity are given in Table 2. x- axis = canonical function 1, y- axis = canonical function 2 (after Baki, 1995).

Setaria viridis . In the case of *E. crus-galli*, reduced tillage enable the weed to proliferate and produced many seeds without any disturbance after emergence, especially in non-weeded plots. Similar patterns were observed in weeded plots, although their populations were understandably lower (Figure 3).

Another problematic graminoid species in the Malaysian rice fields is *Paspalum distichum*. Together with the sedges *C. haspans*, *C. iria* and *Fimbristylis miliacea*, this graminoid was strongly associated with four or five rounds of conventional tillage throughout the experimental seasons of 1991-1993. Arguably, conventional tillage regimes did not appear to reduce the populations of these weed species (Figure 3).

For unknown reasons, *Bacopa rotundifolia* has a reasonably strong association with three rounds of conventional tillage inspective of weeding regimes (Figures 2 & 3) for all seasons. *Rotala rosea*, *L. flava*, *S. guyanensis* and *M. vaginalis*, depicted strong association with zero- or minimal-tillage (Figures 2 & 3). These were so for the 1992-1993 seasons. In 1991, *L. flava*, *R. rosea* and *M. vaginalis* exhibited strong association with plots subjected to zero tillage. This apparent 'shift in association' between broadleaved weeds and tillage regime may be explained by the inherent seed banks retained in the soils from the previous growing seasons and posed problems in subsequent seasons when no control measures were made.

Baki (1995) hypothesised that species groupings into broadleaves, sedges and grasses responded in similar ways to agronomic practices according to their groups. The notable examples were *B. rotundifolia* which was strongly associated with three rounds of conventional tillage while other broadleaves such as *R. rosea*, *S. guyanensis*, *L. flava* and *M. vaginalis* has close affinity to zero- and minimal-tillage regimes (Figures 2 & 3). Such similar responses were not observed with the exception of sedges species within the group. Derksen *et al.* (1994) recorded dissimilar responses among species of the same groupings with different tillage regimes. Further research is needed to elucidate the underlying agroecological attributes that determine the association of species with tillage systems.

(b) Change in water management

Poor water control contributes to increase.. in weed population. This phenomenon related to exposure of the soil to air allowing noxious weeds especially *E. crus-galli* to develop secondary roots (Ampong-Nyarko & De Datta, 1991). Because of that, water seeding of rice is practised in India, Sri Lanka, Malaysia and Thailand. Pregerminated rice is broadcast directly onto the flooded field. The rice, which is seeded into 7-10 cm deep, sinks to the soil, germinates and emerges from the water. The field remain flooded at a depth of 7-10 cm until a few weeks before maturity. This cultural method is used to supress *E. crus-galli*.

(c) Control methods

Weed control methods may affect the weed species growing in association with rice (De Datta, 1977; Janiya & Moody, 1989). Hand weeding is impractical in broadcast seeded rice because it is difficult to distinguish young grassy weeds and rice plants and rice plants may be destroyed in the process. Therefore, herbicides are recognized as the only practical way of for weed control in DSR. When the same herbicides are used continuously in rice without rotation, weeds that tolerate those herbicides could colonize the site. The build-up of populations of a certain weed species after the continuous use of a herbicide can be viewed in two possible ways; first, the weed species is inherently very resistant to the herbicide and the elimination of its competitors favour its predominance; second, the weed species has gradually acquired resistant to the herbicide through continued absorption of the herbicide at sublethal concentrations or through the build-up of the resistant strain of a normally susceptible population (Mercado, 1979). For example, molinate was used to control *E. crus-galli* but escalated the infestation of *L. chinensis*, *I. rugosum* and *E. oryzicola* in Malaysia (Ho, 1991; Azmi & Mashhor, 1994). In the Philippines, *E. glabrescens* (= *E. crus-galli* var. *formosensis*) was dominant in the unweeded and herbicide-treated fields while *M. vaginalis* was dominant in the hand- weeded fields (Mercado, 1979; Janiya & Moody, 1989).

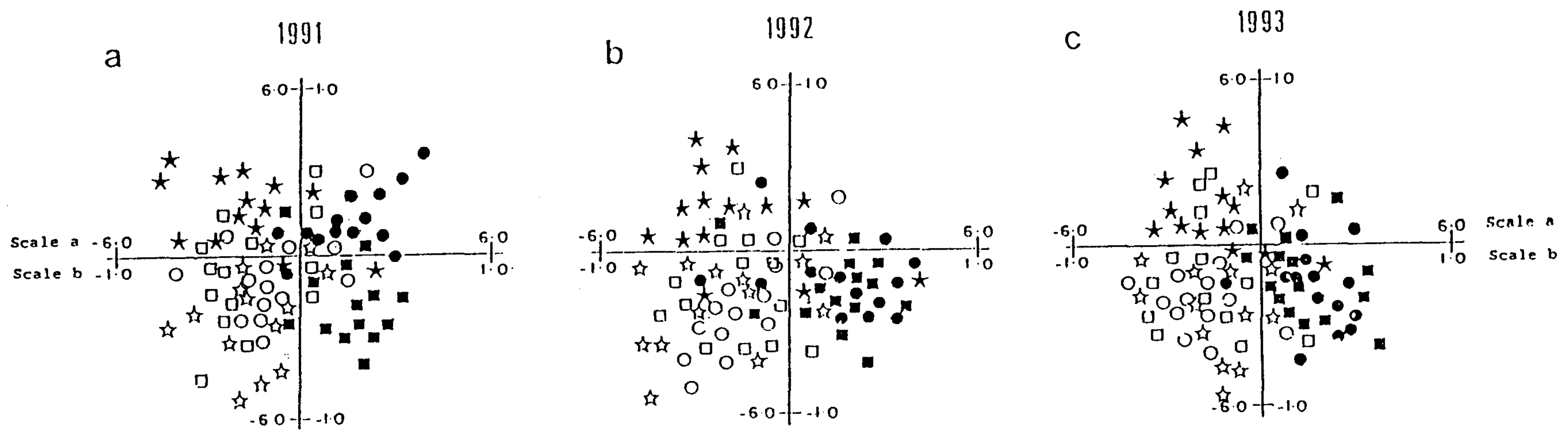


Figure 3: Canonical discriminant analysis ordination diagram of treatment clusters of for zero tillage (●), minimal tillage (■), two rounds (☆), three rounds (☆), four rounds (○) and five rounds of conventional tillage (□) regimes (scale a) and biplot scaling of dominant weed species vectors indicating treatment associations at Bertam in 1991-1993 in plots where no hand weeding was done at 15-30 DAS. Symbols represent individual treatment plots abd their position is located based on relative species composition. Species association with treatment can be asscertained by the direction of the vectors. Vector length indicates the relative strength of association between weed species and the respective tillage regime. Vectors labeled for dominant species which have attributed to community discrimination and species identity are given in Table 2. x- axis = canonical function 1, y- axis = canonical function 2 (after Baki, 1995).

In irrigated areas where herbicides have been used for annual weed control, *E. crus-galli* and *M. vaginalis* have become minor weeds and *Scirpus maritimus* has become increasingly dominant (De Datta, 1977). In rainfed areas, *Paspalum distichum* and *Cynodon dactylon* have become dominant (Mercado, 1979). It has been argued that in the Muda granary of Malaysia, the continuous usage of phenoxy herbicides since 1960's and 1970's has favoured the proliferation of graminoids at the expense of broadleaved weeds especially (Table 2) (Ho, 1991). The 38-fold increase in the use of molinate since 1980 has contributed to the substantial increase in the proliferation of grasses, especially the *E. crus-galli* aggregates in the granary. Baki (unpublished data) argued that the substantial recurrence of broadleaved weeds and sedges in the granary of Tanjung Karang in the 1990's, *vis-a-vis* the 1970's and 1980's, arguably was attributed to the continuous use of graminicides since the last decade by farmers in their effort to arrest weedy graminoids infestation. However, the recent work by Habibah, Baki & Abd. Munir (1995) and Zaharuddin, Baki & Abd. Munir (1995) did not show any meaningful shift in species dominance in weed communities of the Sungei Burong and sawah Sempadan granaries of Tanjung Karang, Malaysia since the published report by Azmi *et al.* (1992).

CONCLUSIONS

Succession or shift of weed species are known to occur in continuously DSR fields in response to tillage practices, technique of crop establishment, weed control practices and other changes in habitat. The shift of weed species from broadleaved weeds and sedges in transplanting method to noxious graminoid in DSR have been observed in tropical Asia where herbicides have been used extensively. This has been particularly evident in the Philippines, Malaysia, Thailand and expected to increase in Indonesia and Vietnam with increasing popularity and importance of DSR gaining in important. The reasons for the increase in noxious weeds are: continuous use of a particular herbicide, decreased use of manual weeding, practice of minimum tillage, saturated conditions during crop establishment in DSR, the use of short-term cultivars and increased use of fertilizers.

Invariably, weed successions in the Asian rice fields can be allogenic or autogenic in nature. The former is driven by forces outside the rice agroecosystem. These forces include change in the amount and duration of available water (either through irrigation or rainfall) and agronomic practices (tillage regimes, methods of rice culture. herbicide regimes and application protocols). The over-reliance by farmers on cheap and readily available phenoxy herbicides in the 1970's and early part of 1980's contribute to proliferation and spread of hard-to-control graminoids like *E. crus-galli*, *L. chinensis* and *I. rugosum*, and of late, weedy rices (*O. sativa*/*O. spontanea*) in many rice fields of Asian tropics. Conversely, the preferential adherence by farmers on graminicides in the 1980's and thereafter to control problematic graminoids rejuvenate yet another cycle of recurrence and prevalence of noxious broadleaves and sedges like *S. zeylanica*, *F. milliacea* to name a few. If intensive weed control is sustained for several years without interruptions, weed species can diminish and species diversity can be reduced (Menges, 1987). On the other hand, the high weed seed populations in the seed banks due to prolific seed production, dormancy and longevity insulate weed population from changes. This is especially true for many weed species in the rice fields of Asian tropics. Autogenic succession, as the name implies, is succession from within the system itself. In the Asian tropics, inter- and intra-specific competitions among neighbouring rice weeds do occur and when they do, displacement of the less competitive species by the competitive ones prevailed. In this context, competitive graminoids like *E. crus-galli* with *phalanx* growth habits will have better chances of preventing the invasion of other competitors for space with a similar habitats than those with *guerilla* growth habits. Furthermore, changes in the habitat may acccelerate species displacement by one another.

Acknowledgements The authors are grateful to Nor Azah Khalid, Anuar Pandak and Rosli Halif for the technical help.

REFERENCES

Akobundu, I.O. (1994). *Weed Science in the Tropics Principles and Practices.* John Wiley & Sons. pp. 521

Ampang-Nyarko, K. and De Datta, S.K. (1989). Ecophysiological studies in relation to weed management strategies in rice. pp. 31-45. *Proceedings of 12th APWSS Conf.*

Ampong-Nyarko, K. & De Datta, S.K. (1991). *A handbook for weed control in rice*, IRRI, Manila, Philippines. 113p.

Azmi, M. (1988). Weed competition in rice production. *Proceedings of the National Seminar and Workshop on rice field weed management (Lam, Y.M., Cheong, A.W. & Azmi, M. eds.).* pp. 141-152.

Azmi, M. & Mashhor, M. (1989). Competition of barnyard grass *(Echinochloa crus-galli)* in direct seeded rice. *Proceedings of the 3rd Inter. Conf. on Plant Protection in the tropics (Anon ed.).* Vol. IV: 224-229.

Azmi, M., Baki, B.B. & Mashhor, M. (1993). Weed communities in principal rice-growing areas in Peninsular Malaysia. *MARDI Report No. 165.* 15p.

Azmi, M. & Mashhor, M. (1994). Weed succession over several seasons of direct seeded rice in Seberang Perai, Malaysia. p.221-224. In: *Proceedings of Plant Protection in the Tropics.* Rajan A. and Ibrahim, Y. (eds). Malaysia Plant protection Society, Kuala Lumpur.

Azmi, M., Watanabe, H., Abdullah, M.Z. & Zainal, A.H. (1994). Padi angin-an emerging threat to direct seeded rice. *Paper presented at the Malaysian Science and Technology Congress, 1994, 15-18 August, Kuala Lumpur.*

Azmi, M. (1994). Biology and control of *Echinochloa crus-galli*(L.) Beauv. in direct seeded rice. PhD thesis, University sains Malaysia.

Baki, B.B. (1995). Effect of tillage regimes and weeding practices on weed communities indirect-seeded rice in Malaysia. *Agronomy Journal* (in press).

Baki, B.B. & Md. Khir (1983). Weeds in major rice growing areas in Peninsular Malaysia: Detection and classification of groups of ecologically related species by multivariate analysis. *Proceedings of the First International Symposium of Weed Science in the Tropics (Rosli, M. & Rajan, A. eds.):* pp. 4-27

Baki, B.B. & Azmi, M. (1992). Integrated management of paddy and aquatic weeds in Malaysia: Current status and prospects for improvement. *Proceedings of FFTC International Symposium on Biological and Integrated Management of Paddy and Aquatic Weeds in Asia.*

Barret, S. (1983). Crop mimicry in weeds. Ecol. Bot. 37:255-287.

Buhler, D.D., Stoltenberg, D.E., Becker, R.L. & Gunsolus, J.L. (1994). Perennial weed populations after 14 years of variable tillage and cropping practices. *Weed Science 42:* 205-9

Casimero, M.C., Cruz, R.T., Objen, S.R. (1994). Weed management in wet-seeded rice in the Philippines. *Paper presented at the Inter. Workshop on Constraints, Oppurtunities and Innovations for Wet-seeded rice. 31 May -3 June 1994, Bangkok, Thailand.* 20p.

Connell, J.H. & Slatyer, R.O. (1977). Mechanisms of succession in natural communities and their role in community stability. *American Naturalist* 111: 1119-44.

De Datta, S.K. (1977). Approaches in the control and management of perennial weeds in rice. In *Proceedings of the 6th Asian-Pacific Weed Science Society Conference,* pp. 204-226.

De Datta, S.K. & Flinn, J.C. (1986). Technology and economics of weed control in croadcast-seeded flooded rice. 51-74p. In: *Proceedingsof the 10th Asian-Pacific Weed Science Conference, Noda, K. and Mercado, B., eds.*

Derksen, D.A., Lafond, G.P., Thomas, A.G., Loeppky, H.A. & Swanton, C.J. (1993). Impact of agronomic practices on weed communities: Tillage Systems. *Weed Science 41:* 409-17

Derksen, D.A., Thomas, A.G., Lapond, G.P., Loeppky, H.A. & Swanton, C.J. (1994). Impact of agronomic practices on weed communities: Fallow within tillage systems. *Weed Science 42:* 184-94

Froud-Williams, R.J., Chancellor, R.J. & Drennen, D.S.H. (1981). Potential changes in weed flora associated with reduced cultivation systems in cereal production in temperate regions. *Weed Research 21:* 99-109

Groves, R.H. (1992). Weed ecology, biology and spread. *Proceedings of the First International Weed Control Congress 1:* 83-88

Habibah, J., Baki, B.B. & Abdul Munir, J. (1995). Spatial pattern analysis of weed community in the rice granary of Sungei Burong, Tanjung Karang, Selangor. *Journal of Bioscience* (in press).

Harper, J.L. (1977).The population biology of plants. Academic Press, London

Ho, N.K. (1991). Comparative ecological studies of weed flora in irrigated rice fields in the Muda area. M. Sc. thesis, Universiti Sains Malaysia. 132p.

Holm, L.G., Plucknett, D.L., Pancho, J.V. & Herberger. (1977). *The World's Worst Weeds, Distribution and Biology,* Univ. Press, Hawai, Honolulu.

Itoh, K. (1991a). Integrated weed management of direct seeded wet rice fields in South East Asia and Pacific Regions, with special reference to Malaysia. *Proceedings of the 13th Asian Pacific Weed Science Society Conference. Oct. 15-18 1991. Jakarta.* pp..

Itoh, K. (1991b). *Life Cycles of Rice Field Weeds and Their Manangement in Malaysia.*Tropical Agriculture Centre, Japan. 89pp .

Kim, K.U. (1994). Ecophysiology of *Echinochloa* species and their management. *FAO-CAB International Workshop on Appropriate Weed Control in South East Asia.* 17-18 May, Kuala Lumpur.

Janiya, J.D. & Moody, K. (1989). weed populations in transplanted and wet-seeded rice as affected by weed control method. *Tropical Pest Management, 35(1)*: 8-11

Lubigan, R.T. & Moody, K. (1989). Effect of herbicides on *Ischaemum rugosum. IRRN 14(2)*: 38-39

Lubigan, R.T. & Vega, M.R. (1971). The effect on yield of the competition with *E. crus-galli* (L.) Beauv. and *Monochoria vaginalis* (Burm. f.) Presl. *The Philippine Agriculturalist.* 210-215p.

Menges, R.H. (1987).Weed seed population dynamics during six years of weed management systems in crop rotations in irrigated soil. *Weed Science 35:* 328-32

Mercado, B.L. (1979). *Introduction to weed science.* Southeast Asian Regional Centre for Graduate Study and Research in Agriculture. pp. 291.

Maun, M.A. & Barret, S.C.H. (1986). The biology of Canadian weeds. 77. *E. crus-galli* (L.) Beauv. *Can. J. Plant Sci. 66:* 739-759.

Moody, K. (1991). Crop-weed complexity in lowland rice. *Proceedings of the 13th Conf. APWSS, Jakarta, Indonesia. 15-18 Oct. 1991.* pp. 15-26.

Moody, K. (1993). Weed-water interactions of direct seeded rice. *Paper presented at workshop on water and direct seeding for rice. 14-16 June. Alor Setar, Kedah, Malaysia.*

Moody, K. (1994). Weedy forms of rice in Southeast Asia. *Paper presented at the Padi Angin Workshop, 18 May, Penang.*

Moody, K. & Drost, D.L. (1981). The role of cropping systems on weeds in rice. *Weed control in rice.* IRRI-IWSS. Laguna, Philippines. 27p.

Pablico, P.P., Yamauchi, M., Tuong, T.P., Cabangon, R.J. & Moody, K. (1994). Crop establishment and weed competitiveness of direct-seeded anaerobic rice cultivar as influenced by seeding and water management systems. *Paper presented at the Inter. Workshop on Constraints, Opportunities and Innovations foe wet-seeded ricce. 31 May-3 June 1994, Bangkok, Thailand.*

Pollard, F. & Cussans, G.W. (1976). The influence of tillage on the weed flora of four sites sown to successive crops of spring barley. *Proceedings 13th British Weed Control Conference 13:* 1019-28

Radosevich, S.R. & Holt, J.S. (1984). *Weed ecology. Implications for vegetation management.* John Wiley & Sons. New York. 265p.

Smith, R.J. Jr. (1983). Weeds of major economic importance in rice and yield losses due to weed competition. In *Proceedings of the Conference on weed control in rice, pp. 19-36. International Rice Research Institute, Los Banos, Philippines, 31 Aug.-4 Sept.*

Smith, R.J. Jr. (1988). Weed thresholds on Southern U.S. rice, *Oryza sativa. Weed Technology 2:* 232-241

Soerjani, M., Kostermans, A.J.G.H. & Tjitrosoepomo, G.T. (1987). *Weeds of rice in Indonesia.* Balai Pustaka, Jakarta. 716p.

Wahab, A.H. & Suhaimi, O. (1990). Padi angin, adverse effect and methods of control (in Malay). *Teknologi Padi 7:* 27-31

Watanabe, H., Azmi, M. & Md. Zuki, I. (1994). Morphological and ecological variation of weedy rice in Muda area. *MADA/MARDI/JIRCAS Report No. 27,*. 41 pp.

Yabuno, T. (1966). Biosystematic study of the genus *Echinochloa. Jap. J. Bot.* ***19*** *:* 227-323.

Zaharuddin, M.S., Baki, B.B. & Abdul Munir, J. (1995). Spatial pattern analysis of weed community in the rice granary of Sawah Sempadan, Tanjung Karang, Selangor. *Pertanika* (in press).

WEEDY RICE PROBLEMS IN SOUTHEAST ASIA AND CONTROL STRATEGY

Hiroaki Watanabe
Japan International Research Center for Agricultural Sciences,
Tsukuba, Ibaraki 305 Japan

Abstract Weedy rice with undesirable traits can inflict crop loss by reducing the yield and quality of commercial rice. Weedy rice rarely grows in transplanted rice, but with the spread of direct seeding culture in southeast Asia, its infestation is increasing. Difficulties in controlling volunteer rice have allowed the fields to be infested by weedy rice. In this region, weedy rice has originated from cultivated rice (*Oryza sativa* L.) or wild rice (other *Oryza* species), and could have developed its ecological weedy characteristics such as easy grain shattering and moderate seed dormancy. It is known as "Padi angin" in Malaysia and "Weedy wild rice" in Thaíland. It is likely that weedy rice will continue to evolve morphologically and metabolically similar to rice crop by inter-crossing with modern cultivars, making it difficult to control using available herbicides. Therefore, integrated control measures based on ecological methods should be applied to overcome the problems. Genetic and ecological studies would give useful information for developing its control strategy.

Key words weedy rice, wild rice, volunteer rice, easy shattering, seed dormancy

Introduction In a region where a crop shows a high genetic diversity, the crop is often associated with its companion weed such as weed sorghum, weed oat, and weed rice(Oka, 1988). In rice fields where rice and its weedy form grow together, detection of weedy rice is rather difficult since it often shows continuous variation in its morphologies closely similar(mimic) to rice crop. Weed is defined biologically as a plant adapted to unstable and frequently irregularly disturbed habitat including agricultural fields (Kawano, 1969). Weed has also been defined by its undesirable behavior to the activities of man(Mortimer, 1990), even though weed include some useful or available plants for man by the recent definition (Kusanagi, 1994). In this paper, "weedy rice" is the term used to describe the rice plant adapted to rice fields and not wanted by farmers because of its interfering with rice production.

Weedy rice in rice fields have been reported in many countries, and called by various local names as "Red rice" in the USA, "Akamai" in Japan, "Lutao" in China, "Sharei" and "Salpeh" in Korea, "Khao pa" in Laos and "Khao nok" in Thailand (Smith, 1981, Hyakutake et al., 1983, Oka, 1988, Kim, 1993, Vaughan, 1994a). In Tropical Asia, weedy rice problems have also been observed in India, Philippines, Vietnam and Myanmar(Oka, 1988, Moody, 1994, Vaughan, 1994b). Infestation of "Padi angin", Malaysian weedy rice inflicting rice production by its easy grain shattering, was observed in Projek Barat Laut Selangor in 1988 (Wahab and Suhaimi, 1990), and the problem was detected in 1990 in the Muda rice area(Md. Zuki and Kamarudin, 1994). Weedy rice infestation is serious in direct seeded rice fields, and is supposed to be increasing with spread of direct seeding rice culture in tropical Asia. Objective of this paper is to present information on some important characteristics of weedy rice with respect to its problems in rice production, morphological variation and adaptability in rice fields with special reference to Malaysian weedy rice. Future development of its control strategy will also be discussed.

Origin of weedy rice In the temperate region where wild rice does not grow, weedy rice has evolved from rice(*Oryza sativa* L.), although origin of "Lutao" in China and "Sharei" in Korea is unknown. The origin of weedy rice in areas where rice and wild rice are sympatric may be more complicated. Rice in Asian countries is thought to be derived from common wild rice(*Oryza rufipogon* Griff. = Asian form of *O. perennis* Moench), and progenies of hybridization between cultivated rice and its wild relative are often weed in lowland rice(Morishima, 1987). Common wild rice itself exhibits wide variation in life-history traits, and its annual type (sometimes named as *O. nivara* or *O. sativa* f. *spontanea*) are adapted to disturbed habitats characterized by a prolonged dry season(Oka, 1988). These species have the same number of chromosomes (2n=24, genome AA), and their F1 hybrids show no disturbance in meiotic chromosome pairing(Chu et al., 1969). Therefore, not only cultivated rice but also annual or intermediate type of common wild rice and their natural hybrids are a possible origin of weedy rice in tropical Asia, although differentiation of the annual or intermediate type depends on environmental conditions.

Asia can be divided into two areas based on the distribution of annual and intermediate types of wild rice compared to perennial wild rice. India, Nepal, Sri Lanka, Bangladesh, Thailand, Cambodia, Laos, Myanmar and parts of southern Vietnam have a long dry season. In these countries annual and intermediate type of common wild rice can commonly be observed (Morishima et al., 1961, Morishima and Oka, 1975, Oka, 1988, Vaughan, 1994a). The life-history traits of annual, intermediate and perennial type has been compared(Barbier, 1989a, 1989b). Sano(1980) concluded that the intermediate type has high evolutionary potential, and therefore is more likely to be the wild progenitor of rice(*O. sativa*) than the typical perennial type. Common wild rice which grows in rice fields and is considered a serious weed was identified as annual or intermediate type in Thailand (Hyakutake et al., 1983a, 1983b, 1984). Wild rice population found in a stream running through glutinous rice field in Chiengmai, Thailand, contained many heterozygotes for the glutinous gene(Oka and Chang, 1961), and population found in India was also shown to be a hybrid swarm between wild and cultivated rice. Therefore, common wild rice and their resultant hybrids with rice cultivars might be an important progenitor of weedy rice in Thailand and India.

On the other hand, in the tropical rain forest area of Malaysia and Indonesia, differentiation of annual or intermediate types of common wild rice has rarely occurred. Thirty-two samples of common wild rice from Peninsular Malaysia were all perennial type(Abdullah et al., 1991). It grows along irrigation canals, roadside ditches, swamps in secondary drains adjacent to rice fields, banks of old canals, and corners of rice fields(Itoh et al., 1990). Perennial common wild rice itself is supposed to have little potential to be a serious weed in well managed rice fields. A population of weedy rice growing in a dry seeded rice field in Malaysia showed wide variation in its morphologies(Watanabe et al., 1994). DNA analysis using randomly amplified polymorphic DNA(RAPD) markers revealed that genetic structure of these rice plants showed close similarity to cultivated rice(Abdullah et al., 1994), indicating that the Malaysian weedy rice could have originated from cultivated rice, although the gene transfer from common wild rice can occur.

In early August of 1994, common wild rice was observed flowering at the roadside adjacent to a rice field in the Muda area, Peninsular Malaysia. It was suspected to be an intermediate wild rice because it exhibits weak photoperiodism and higher seed fertility, compared to typical perennial type which flowers from late September to late January(Itoh et al., 1990). The Muda area is characterized by a short dry season for two months. Its habitat is more disturbed than that of most perennial populations due to regular cleaning of roadside ditches. Relationship between the intermediate type of common wild rice and weedy rice is unknown in Malaysia.

Serious infestation and problems in Malaysia The commencement of double cropping in 1970 followed by direct seeding culture in 1980's had caused weed shift and serious weed infestation in the Muda area(Ho, 1991, Itoh, 1991, Morooka and Yasunobu, 1993). At the beginning, wet seeding was mainly practiced. Dry seeding was practiced in the fields where enough water was not supplied in off-seasons. Seedling establishment in dry seeded fields is more unstable compared to wet seeding because it depends on uncertain rainfall. Poor establishment of dry seeded rice was sometimes compensated by volunteer seedlings which emerged from shed seeds in the previous season. In the first season(off-season) of 1987 when irrigation water was not supplied in the Muda area, volunteer seedling culture was practiced in nearly 40% of total rice fields, where farmers depended on volunteer rice seedlings for the season crop. Volunteer seedling culture has decreased in off-seasons from 1988 to early 1990's, when dry seeding culture was encouraged to save irrigation water because of continuous shortage of water supply from irrigation dams (Fujii and Cho, 1993). According to the field survey in 1988 and 1989, rice crops in dry seeded fields included a lot of volunteer seedlings(Hiraoka et al., 1991). Weedy rice with easy grain shattering trait emerged with volunteer seedlings. The problem was detected in 1990, and became obvious in 1993 in the Muda area, where a total of 168 ha were infested with weedy rice (Md. Zuki and Kamarudin, 1994).

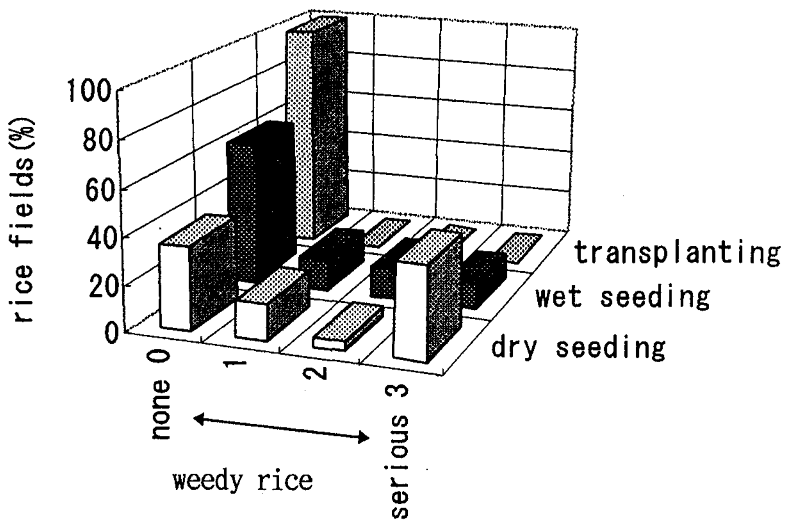


Figure 1 Weedy rice infestation in Different cultivation methods

An interview survey was carried out in the Muda and Tanjung Karang rice area to investigate relationship between cultivation method and weedy rice infestation. Eighty three farmers were selected for the survey whose fields were infested by weedy rice in 1994. According to the farmers' responses on their cultivation from I/1993 to I/1994, infestation of weedy rice was more serious in dry seeded fields(Figure 1). Practice of dry seeding culture associated with volunteer rice seedlings is supposed to be the most important factor causing infestation of weedy rice in Malaysia. Weedy rice infestation, however, was also observed in wet seeded rice fields. It suggested that weedy rice had adapted to puddled soil condition, and that broadcasted seeds had been contaminated with weedy rice seeds. Crop Production Center(CPC) is providing seeds of several modern rice cultivars. However, its capacity of seed production is not enough for rice cultivation in the whole Muda area. More than two thirds of planted area is suspected using farmers' own seeds from the previous crop. Therefore, seed contamination is considered as a factor that increase weedy rice problem in the area.

Undesirable traits of weedy rice in rice production are listed in Table 1. Weedy rice reduces rice yield and causes lodging problem when its grows at a high density. In a serious infested field where weedy rice plants occupied 35% of total rice plants, the rice grain yield was 3.2 ton/ha, which was 50% to 60% of the rice yield without weedy rice infestation(Watanabe et al., 1994). In the dry seeded fields, weedy rice emerged earlier than seeded cultivated rice since it emerged from incorporated seeds in the soil, resulting in its competitive advantages over cultivated rice with poor seedling establishment.

Table 1 Undesirable traits of weedy rice including evolutional characteristics in rice production in Malaysia

	undesirable traits	interfering to rice production
morphological characteristics	long culm	causing lodging, high competitive advantage over rice
	short grain pigmented grain pigmented pericarp awn	reducing rice quality
	mimicry to rice	difficulties in identification
ecological characteristics	easy grain shattering	reducing rice yield, increasing seed population in soil
	seed dormancy	difficulties in controlling after shedding
	seed viability in the soil	difficulties in reducing seed population in rice fields
	variability in germination traits	adaptability in wet seeded fields
physiological characteristics	tolerance to rice herbicides	less effectiveness of chemical control

Some rice farmers in Malaysia seemed to be less concerned with the quality of their harvested rice according to the survey. However, the grain grade will be estimated lower when it is contaminated with short grains of weedy rice. Pigmented and/or awned grain and colored pericarp will also reduce the quality of rice grains. Farmers, who cultivate short maturation cultivar to avoid yield loss by early shattering weedy rice, will harvest a lot of weedy rice grains. Mimicry to cultivated rice, seed dormancy and tolerance to rice herbicides are also undesirable characteristics. They cause difficulties in controlling weedy rice, which cost farmer for eliminating it and reduce his net income.

Variation in morphologies Weedy rice plants showed differences in culm length, leaf colour, grain size, grain and pericarp pigmentation, awn, panicle type and panicle length in Malaysia (Wahab and Suhaimi, 1991, Azmi et al., 1994). Some of the classified characteristics resembled the morphologies of "Mahsuri", a rice cultivar with long culm and moderate to easy grain shattering traits, which farmers used to grow before introduction of direct seeded rice culture. Detail survey on their morphologies in a dry seeded rice field showed that majority(93%) of weedy rice plants had longer culms than cultivated rice (modern cultivar), 34% had pigmented grains, and 39% had grains with long awn, while the population included some easy shattering plants with short culms and non-pigmented awnless grains (Watanabe et al., 1994). These morphological characteristics was supposed to be distributed independently from each other in the population.

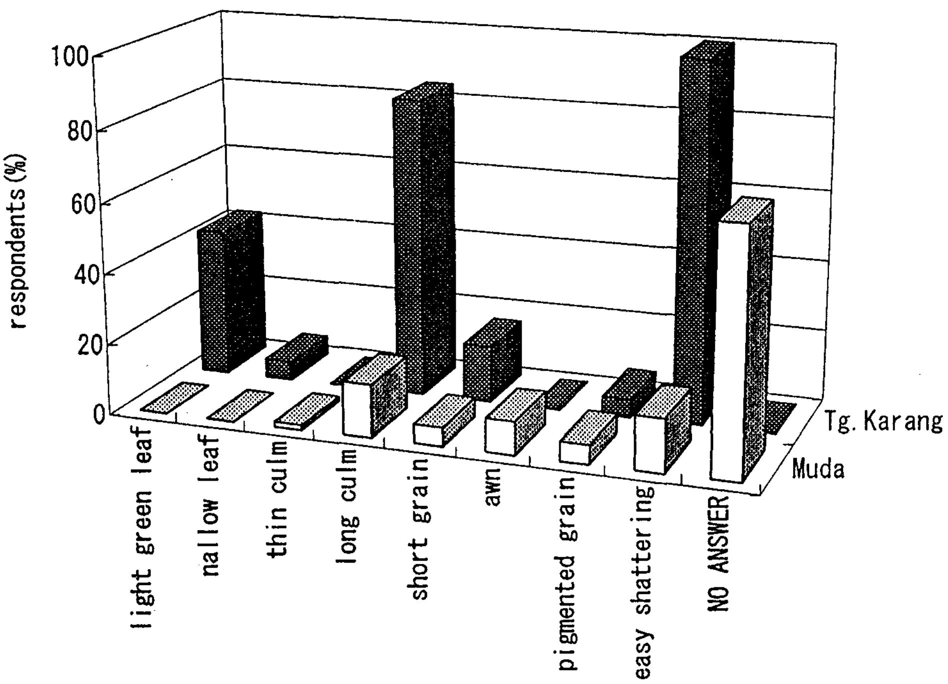


Figure 2 Result of interview surveyon characteristics for farmer's identification of weedy rice in the Muda and Tg. Karang area, Peninsular Malaysia

According to the survey on identification method of weedy rice, more than a half of Muda farmers did not have any identification method (Figure 1). It was due to a limited experience of weedy rice infestation compared to farmers in Tg. Karang area where the weedy rice problem occurred earlier. Long culm, short grain and its pigmentation were the morphologies for identification after heading in both areas. Light green color of leaf sheath was useful identification for farmers who controlled weedy rice at early stage of rice cultivation in Tg. Karang area. However, no farmer could identify the weedy rice with the same morphologies as cultivated rice. Several plants with easy grain shattering traits which were resembled modern rice cultivar(MR-84) were found in direct seeded rice fields in Malaysia(Vaughan, 1994 personal communication).

Easy grain shattering and seed dormancy Seventeen variants of Malaysian weedy rice showed wide variation in their seed shedding behavior(Watanabe et al., 1994). Grain shattering started at eight days after heading in the earliest shattering type, and earlier shattering resulted higher shattering rate. Some variants showed less grain shattering as modern cultivars, MR-84 and MR-123. Vaughan(1994b) classified their shedding performance into several grades as hard threshing, easy threshing, very easy threshing, easy shattering, very easy shattering, and spontaneous shattering.

According to the germination test using seeds of twenty weedy rice plants growing in a rice field in Malaysia, seed dormancy was absent at three months after shedding, although their germination was not uniform compared to MR-84 (Watanabe et al., 1994). However, germination test using fresh dry seeds at immediately after seed shedding showed wide variation in seed dormancy(Figure 3), suggesting that Malaysian weedy rice required less than three months to overcome its seed dormancy. This trait may be desirable for weedy rice to emerge in the next season of double rice cropping in Malaysia.

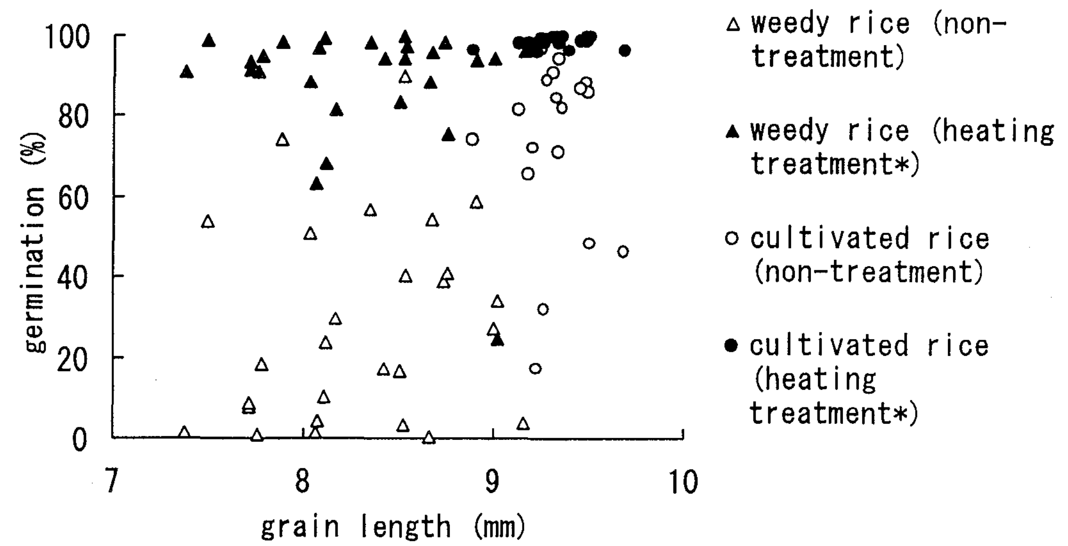


Figure 3 Seed germination of weedy rice and cultivated rice collected from twenty six rice fields in Malaysia
(* heating treatment: 50°C for sevendays before germination test)

The two ecological characteristics, seed shattering and its dormancy, are related to adaptability in rice fields. Weedy rice strains from Thailand, India, Korea and Nepal were varied in seed shedding rate and in the number of days required to overcome dormancy, while so-called "red rice" from Japan, Korea and Brazil had a low shedding rate and low degree of seed dormancy (Oka, 1988). The differences in seed shattering pattern and their dormancy of progenies of three variants growing in a rice field in Malaysia was estimated (Figure 4). Variant 1 seemed to be the easy shattering type as intermediate between hard shattering and spontaneous shattering, while variant 2 and variant 3 seemed to be the spontaneous shattering type which started to shed seeds earlier and completed in several days. Seed germination percentage is higher in the progenies of variant 1 than that of variant 2 and variant 3, indicating that degree of seed dormancy of spontaneous shattering type was higher than that of intermediate shattering type. It clearly demonstrated that there was genetic variation in ecological characteristics in the population, because these different types grew together in the rice field.

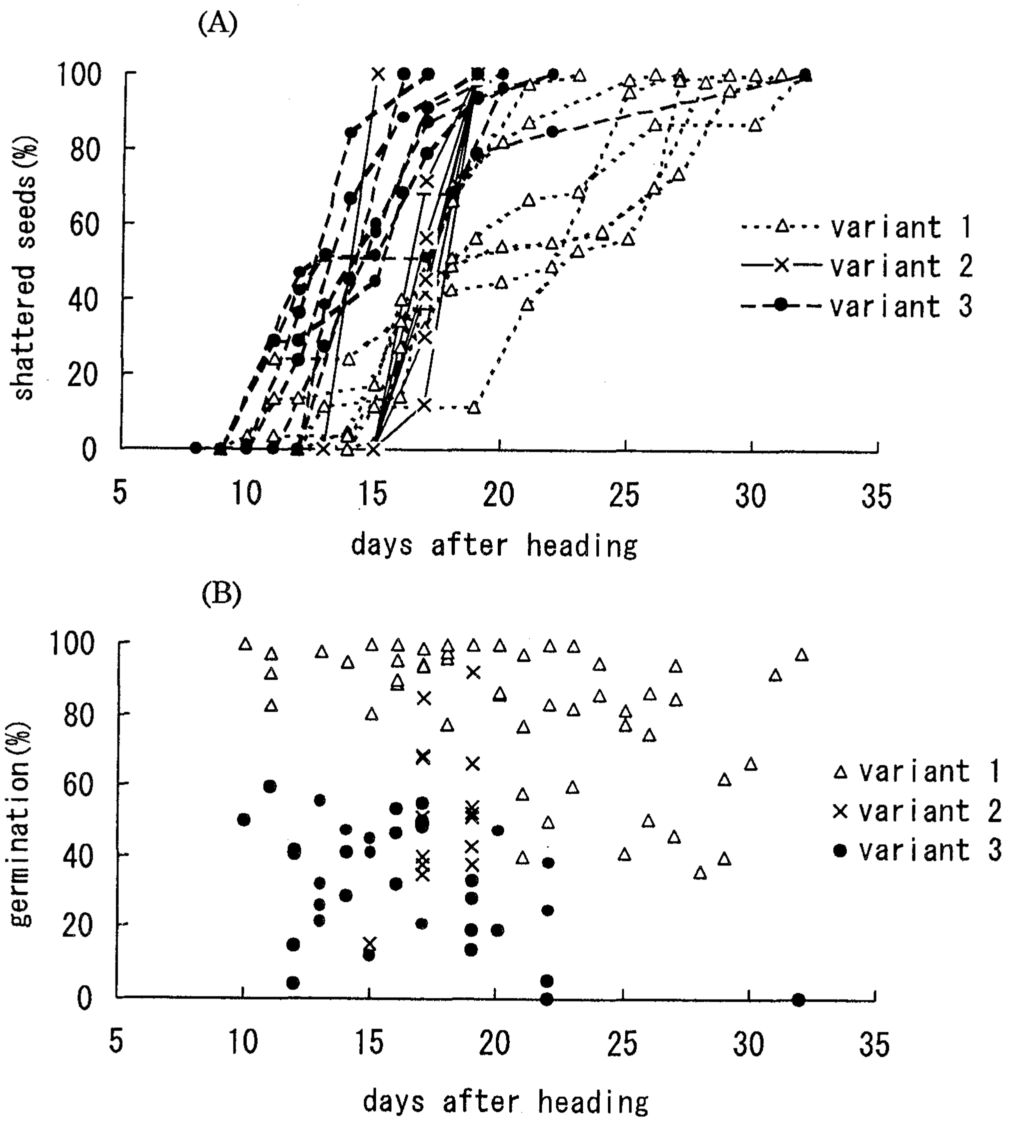
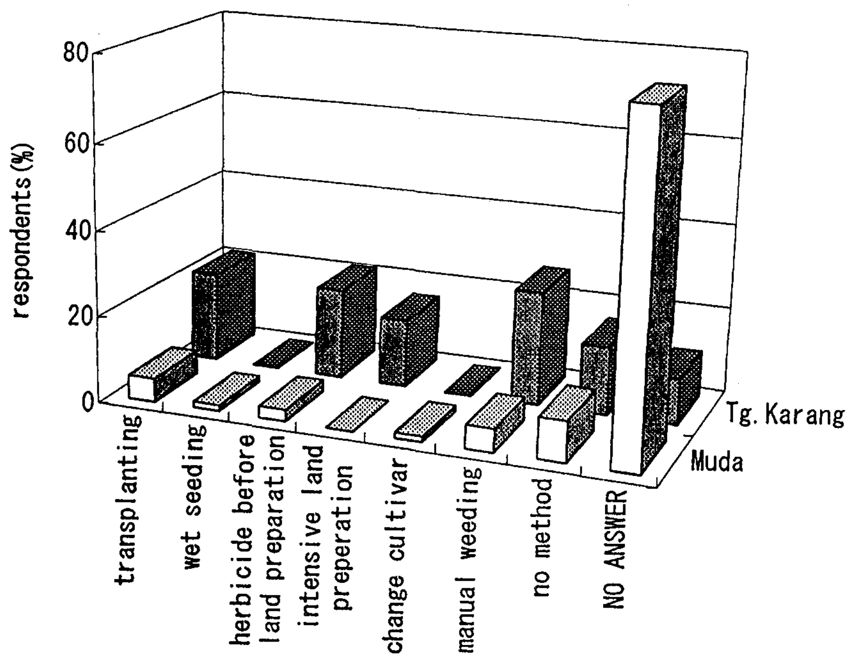


Figure 4 Seed shattering of weedy rice sampled from the Muda area(A) and germination percentage of shattered seeds(B)

Control of weedy rice Manual transplanting has prevented rice fields from weedy rice infestation. Zainal and Azmi(1994) reported that farmers in the infested areas who reverted back to transplanting culture had completely avoided regeneration of weedy rice. In direct seeding culture, however, no single technique has superior effectiveness in controlling it. Interview survey is indicating that many farmers were puzzled over difficulties in controlling weedy rice in Malaysia(Figure 5). Several control measures should be integrated to eliminate it(Table 2).



Figire 5 Result of interview survey on effective control methods of weedy rice in the Muda and Tg. Karang area, Peninsular Malaysia

(1) Land preparation Weedy rice which adapted to rice fields have seed dormancy, more or less, even it evolved from cultivated rice. However, repeated rotovation is effective to reduce weedy rice population in rice fields. Weedy rice seedlings which are promoted to emerge by the first or the second rotovation will be buried in the soil by the second or the third rotovation. In dry seeding rice culture, intensive land preparation is effective in getting uniform seedling establishment of broadcasted rice as well as reducing weedy rice population. The use of drive harrow was recommended to make soil lumps smaller in size(Fujii and Cho, 1993). In wet seeding culture, intensive puddling is effective on reducing weedy rice emergence and also on reducing other aerobic germinating weeds and some perennial weeds.

Table 2 Effectiveness of cultural practices on reducing weedy rice population in tropical rice fields.

cultural practice	negative effect ←——→ positive effect	effectiveness(1)	note(2)
herbicide before land preparation (3)	not apply ←——→ apply	****	A
land preparation (3)	poor ←——→ intensive	*****	A,B
seed purity	contaminated ←——→ pure	***	C
seed vigor	weak ←——→ strong	**	B,D
cultivation method	dry seeding wet seeding transplanting	*****	A,B,D
seeding method(wet)	broadcasting ←——→ row seeding	***	B,E
seeding method(dry)	broadcasting row seeding drill seeding	***	B,E
seed rate	low density ←——→ high density	**	D
water management at seedling establishment (wet seeding)	no standing water←——→well drainage	**	B
water management after seedling establishment	no standing water ←——→ flooded	*	A,D
herbicide usage in rice (4)	foliage soil treatment soil incorporation	*	A
manual weeding	none ←——→ intensive	*****	A
fertilizer usage (3)	before weed control ←→after weed control	*	D
harvesting (3)	early or late ←——→ right timing	*	C,F

(1) Less effectiveness* to superior effectiveness*****
(2) Effective on; A: reducing volunteer rice seedlings including weedy rice
B: uniform seedling establishment
C: preventing from contamination of weedy rice
D: desirable rice growth and high competitive advantages over weedy rice
E: minimizing of difficulties in manual weeding
F: preventing from shattering of weedy rice seeds
(3) Timing of practices is important
(4) Few registered herbicide is available for tropical rice fields

(2) Seed purity and vigor Pure seeds could be harvested in pure field. Intensive rice cultivation is necessary for seed production. Selection of seeds with high vigor is related to good seedling establishment and desirable rice growth competitive to weedy rice.

(3) Seedling establishment Uniform and rapid seedling establishment of cultivated rice is necessary to prevent serious weed infestation including weedy rice. In dry seeding culture under severe draught condition, seedling establishment depends on attachment of seed surface with soil. Tillage for mixing seeds with soil and pressing the soil with roller after sowing were recommended from the result of field experiment under MADA/JIRCAS joint research program(Fujii and Cho, 1993). In wet seeding culture, remaining water in the fields after drainage causes the formation of vacant spot where weeds will emerge later. Therefore, well water drainage is necessary in seedling establishment period. After seedling establishment, field should be submerged by water and fertilizer should be applied for desirable rice growth. Timing of fertilizer application will be important for its competitive advantages over weedy rice.

(4) Manual weeding Many farmers noticed that manual weeding is the most effective practice for controlling weedy rice. However, it cost farmers physically and economically. Moreover, there are difficulties in walking in broadcasted rice fields and identification of weedy rice. Making narrow ditch to walk in the field, row seeding or drill seeding will help farmers to practice manual weeding. Successful farmers who eliminate weedy rice by manual weeding, has made effort to reduce emergence of weedy rice by the other methods.

(5) Chemical control Herbicide usage before land preparation is effective to reduce seed population of weedy rice in the field. Paraquat, glufosinate and glyphosate are available, and rotovation after herbicide usage will increase their effectiveness.

Few herbicide, however, is available to control after seeding in direct seeded rice fields in tropical Asia, although butachlor and oxadiazon was effective on controlling volunteer rice in transplanted rice in Japan(Nemoto et al., 1982). Several field experiments were carried out to control red rice in the USA. Treatment of preplant soil-incorporated molinate at 4.5 and 6.7 kg/ha in a continuously flooded culture or 6.7 kg/ha in an alternately drained-flooded culture controlled 87 to 93% of red rice, resulting high grain yield and high grain quality, while water culture treatments without molinate did not control red rice(Smith, 1981). Baker et al.(1986) concluded that pre-plant incorporated molinate at 4.5 kg/ha with brief post seeding drainage give the best red rice control. Effectiveness of molinate was also evaluated on padi angin, Malaysian weedy rice(Lo, 1994). From the field experiment, incorporative treatment of molinate at 4.5 kg/ha immediately before seeding was the most effective on padi angin control. Lo suggested that cultivated rice could have advantages over padi angin on stronger seedling vigor from broadcasted fresh seeds, resulting the differential effect of molinate between cultivar and padi angin.

6) Control strategy in future Breeding of rice highly tolerant to herbicide would help chemical control of weedy rice. Rechard and Baker(1979) evaluated the response of seventy-three rice cultivars to molinate. They were divided into five grades from highly susceptible to highly tolerant, showing the possibility to develop cultivars which have a high tolerance to molinate. Tissue culture and other

biotechnology developed rice plants resistant to AHAS-inhibiting herbicides from the mutant cells in Rice Research Station in Crowley(Croughan, 1994). Transgenic rice lines resistant to glufosinate, a broad spectrum herbicide, were developed by Agracetus, Inc. from two rice cultivars, and their response to the herbicide were evaluated in RRSC(Braverman, 1994). Transgenic lines from Gulumont showed no apparent injury by glufosinate. Koshihikari lines displayed some initial yellowing shortly after herbicide treatment, but these symptoms had disappeared by 14 days after treatment.

Weedy rice will continue to evolve physiologically and metabolically similar to rice cultivars. Continuous usage of herbicide resistant cultivar would cause herbicide resistant weedy rice through the crossing and natural selection in rice fields. Segregation in heading time and culm length in progenies of weedy rice plants indicated that the rice field was infested by heterogeneous rice plants(Watanabe et al., 1994). Genetic structure of common wild rice was influenced by its mating system in natural population(Morishima and Barbier, 1990). Information on mating performance of weedy rice, gene transferring between weedy rice and cultivated rice and their genetic structure in rice fields is necessary for further discussion on evolution of weedy rice.

Acknowledgment Presented information on Malaysian weedy rice are provided by collaborative research program between Malaysian Research and Development Institute, Muda Agriculture Development Authority and Japan International Research Center for Agricultural Sciences with kind cooperation of National Institute of Agriculture Resources. The author wishes to express his sincere gratitude to Dr. Shariff Ahmad, Director General of MARDI, Dato' Syed Azizan Syed Mohamad Al-Idrus, General Manager of MADA and Dr. Keiji Kainuma, Director General of JIRCAS, and special thanks to Dr. Azmi Man and Mr. Abdullah Zain(MARDI), Mr. Ho Nai Kin and Mr. Md. Zuki Ismail(MADA), and Dr. Kazutoshi Okuno and Dr. Duncan A. Vaughan(NIAR), and all their staff members.

References

Abdullah M. Z., A. D. Vaughan and Mohammad O. (1991) Wild relatives of rice in Malaysia: Their characteristics, distribution, ecology and potential in rice breeding. MARDI Report No. 145, 28 pp.

Abdullah M. Z., H. Watanabe, D. A. Vaughan and K. Okuno (1994) Padi Angin: Its probable origin and diversity revealed through DNA polymorphism. Proc. of the 1st National congress on Genetics, Kuala Lumpur, Malaysia, 164-167.

Azmi M., H. Watanabe and Abdullah M. Z. (1994) Morphological characteristics of Padi Angin. Paper presented at MARDI Workshop on Padi Angin, 18 May 1994, Kepala Batas, Seberang Perai, Malaysia. 17 pp.

Baker, J. B., E. A. Sonnier and J. M. Shrefler (1986) Integration of molinate use with water management for red rice (*Oryza sativa*). Weed Sci. 34, 916-922.

Barbier, P. (1989a) Genetic variation and ecotypic differentiation in the wild rice species *Oryza rufipogon*. I. population differentiation in life-history traits and isozynic loci. Jpn. J. Genet. 64, 259-271.

Barbier, P. (1989b) Genetic variation and ecotypic differentiation in the wild rice species *Oryza rufipogon*. I. Influence of the mating system and life-history on the genetic structure of population. Jpn. J. Genet. 64, 273-285.

Braverman, M. P. (1994) Field evaluation of genetically engineered glufosinate resistant rice lines. Louisiana Agriculture 37(3), 29 p.

Chu, Y-E., H. Morishima and H. Oka (1969) Reproductive barriers distributed in cultivated rice species and their wild relatives. Jpn. J. Genet. 44, 207-223.

Croughan, T. P. (1994) Application of tissue culture techniques to the development of herbicide resistant rice. Louisiana Agriculture 37(3), 25-26.

Fujii, H. and M-C. Cho(1993) Studies on water management under direct seeding in the Muda area, Malaysia. MADA/JIRCAS Final Report, 217 pp.

Hiraoka, H., N-K. Ho and G. Wada (1991) The establishment of direct seeding rice cultivation in the Muda irrigation scheme of Malaysia. MADA/TARC Final Report, 142 pp.

Ho, N-K. (1991) Comparative ecological studies of weed flora in irrigated rice fields in the Muda area. MADA Monograph No. 44, 97 pp.

Hyakutake, H., Prasarn V., Chaiyot S. and Siriporn Z. (1983a) Distribution and habitat of wild rice in deep-water rice and other areas in Thailand. Weed Research, Japan 28 (suppl. I), 181-182.

Hyakutake, H., Siriporn Z. and Chaiyot S. (1983b) Some ecological characters of wild rice(*Oryza rufipogon*) in deep-water rice areas in Thailand. Weed Research, Japan 28, 183-184.

Hyakutake, H., Siriporn Z., Prasarn V. and Chaiyot S. (1984) Ecological characteristics of weedy wild rice in Thailand (in Japanese). Weed Research, Japan 29(suppl. I), 89-90.

Itoh, K., Abdullah M. Z. and Azmi M. (1990) Habitats of four species of wild rice in Malaysia. Proceedings of the 3rd Tropical Weed Science Conference, Kuala Lumpur, Malaysia, 377-384.

Itoh, K .(1991) Integrated weed management of direct seeded wet rice fields in south-east Asia and Pacific regions, with special reference to Malaysia. Proceedings I of the 13th Asian Weed Science Society Conference, Jakarta, Indonesia, 77-94.

Kim, S-C. (1993) Effective weed control technology for dry seeded rice in Korea. Proceedings I of the 10th Australian and 14th Asian Pacific Weed Science Society Conference, Brisbane, Australia, 144-148.

Kusanagi, T. (1994) A concept of weed and weed science(in Japanese). "Weed Management Handbook (First edition)", Asakura press, 2-6.

Lo, N-P. (1994) Chemical control of 'Padi Angin'(*Oryza sativa*). Paper presented at MARDI Workshop on Padi Angin, 18 May 1994, Kepala Batas, Seberang Perai, Malaysia. 10 pp.

Md. Zuki I. and Kamarudin D. (1994) Status dan kawalan 'Padi Angin' di kawasan MADA (in Malay). Paper presented at MARDI Workshop on Padi Angin, 18 May 1994, Kepala Batas, Seberang Perai, Malaysia. 20 pp.

Moody, K. (1994) Weedy forms of rice in Southeast Asia. Paper presented at MARDI Workshop on Padi Angin, 18 May 1994, Kepala Batas, Seberang Perai, Malaysia. 5 pp.

Morishima, H., H. Oka and W-T. Chang (1961) Directions of differentiation in population of wild rice, *Oryza perennis* and *O. sativa* f. *spontanea*. Evolution 15, 326-339.

Morishima, H. and H. Oka (1975) Comparison of growth pattern and phenotypic plasticity between wild and cultivated rice strains. Jpn. J. Genet. 50(1), 53-65.

Morishima, H. (1987) Wild rice in southeast Asia -Its variation and ecology- (in Japanese). GAKUJUTSU GEPPOU 40, 719-723.

Morishima, H. and P. Barbier (1990) Mating system and genetic structure of natural populations in wild rice *Oryza rufipogon*. Plant species Biol. 5, 31-39.

Morooka, Y. and K. Yasunobu (1993) Direct seeding culture and weed problems under double cropping in the Muda plain(in Japanese), Malaysia. Technical Document of TARC No. 19, 159 pp.

Mortimer, A. M. (1990) 1/The biology of weeds. "Weed control hand book(Eighth edition)", Blackwell Scientific Publications, Oxford. 1-42.

Nemoto, H., E. Nakagawa and H. Hanawa (1982) Control of volunteer rice in rice cultivation for seed production(in Japanese). NOGYO OYOBI ENGEI 57(3), 465-467.

Oka, H. and W-T. Chang (1961) Hybrid swarms between wild and cultivated rice species, *Oryza perennis* and *O. sativa*. Evolution 15, 418-430.

Oka, H. (1988) Origin of cultivated rice. Japan Scientific Societies Press.

Rechard, E. P. Jr. and J. B. Baker (1979) Response of selected rice (*Oryza sativa*) lines to molinate. Weed Sci. 27, 217-223.

Sano, Y., H. Morishima, H. Oka (1980) Intermediate perennial-annual populations of Oryza perennis found in Thailand and their evolutionary significance. Bot. Mag. Tokyo 93, 291-305.

Smith, R. J. Jr. (1981) Control of red rice (*Oryza sativa*) in water-seeded rice(*O. sativa*). Weed Sci. 29, 663-666.

Vaughan, D. A. (1994a) The wild relatives of rice, A genetic resources handbook. International Rice Research Institute, Los Banos, Philippines, 137 pp.

Vaughan, D. A. (1994b) Preliminary report on field trip to Malaysia to study Padi angin (mimeograph). Paper presented to MARDI, JIRCAS and NIAR, August 1994.

Wahab, A. H. and Suhaimi O. (1991) Padi angin-characteristics, adverse effects and methods of its eradication (in Malay with English abstract). Teknol. Padi. 7, 21-31.

Watanabe, H., Azmi M. and Md. Zuki I. (1994) Morphological and ecological variation of weedy rice in the Muda area. MADA/MARDI/JIRCAS Quarterly Meeting Report, No. 27, 41 pp.

Zainal A. H. and Azmi M. (1994) Kawalan kultura padi angin(in Malay). Paper presented at MARDI Workshop on Padi Angin, 18 May 1994, Kepala Batas, Seberang Perai, Malaysia. 7 pp.

Implementation of Integrated Weed Management for Sustainable Rice Production

Prasan Vongsaroj

Botany and Weed Science Division, Department of Agriculture, Chatuchak, Bangkok 10900, Thailand

Abstract A single weed control is not sufficient for sustainable rice production and integeration of weed management methods is neccessary. Land preparation is the primary method for destroying weeds and germination weed seeds, by land levelling in transplanted rice and pregerminated direct--seeded rice; by repetition of tillage prior to seeding seeded rice. After the crop is established, rice varieties with long and droopy leaves such as IR 2006-P-3-33-2, Kim Rad F87, Dular and Hashkalmi well have better competition for light and reduce the biomass of weeds. For transplanted rice, water should be used as a tool to control weeds by mintaining it as 5-10 cm one month after transplanting. With pre-germinated direct-seeded rice, water should be drained one week after seeding. Weed control by manual weeding or small machine at 20-30 days after planting is usually necessary. Control of weeds by judicious use of herbicides 2,4-D butachlor, thiobencarb, pretilachlor, oxadiazon, and fenoxaprop-p-ethyl and the possibilites of substitution by other bio-agents such as duck agisting and azolla coverage of weed is discussed.

Key words : integrated weed management, sustainble rice production, lowland rice, upland rice and deepwater rice

Introduction A single method of weed control is ususally not successful. Weed management is a combination of practices that lead to sustainable rice production. Weed management is long-term and aims to optimize farm productivity, by maintaining weeds below levels which compete significantly with the crop. It must maintain a balance between economic, social and emviromental considerations (Kon, 1992). Weed management is a combination of several factors, including rice cultivars, planting methods, land preparation, jucidious irrigation, time of planting, crop rotation, harvesting method, biological control agents, allelopathic subatances, preventive weed control methods and jucidious chemical weed control (Smith, Jr., 1993). Sustainable rice production should depend on decreased use of chemicals and other fossilbased inputs, while the same time increase yield, reduce production costs, improve farm profit, reduce risk, and sustain the productivity of the soil and water resources (Harwood, 1990). Consideration of each method of weed control for inclusion in weed management different rice cultivation type is important to achieve sustainable rice production.

Land preparation Land preparation is an extermely important weed control practice. It can provide weed free conditions at planting and provide favorable conditions for the growth and development of the crop. In the past, when plowing was carried out using draft animals, it was done when the soil was wet and the majority of weeds had germinated. Weed seedings were killed because ploughing uprooted them and covered them with soil. Now that tractors are being used, plowing can be carried out under dry conditions. Newly shed weed seeds lying on the soil surface are buried deep in soil, while buried seeds from the previous season are brought up to the surface to germinate. This therefore the causes severe weed infestations, especially in upland rice and dry seeded rice. Soil should be harrowed after the first plowing, when weeds have reached the seeding stage. This will kill the majority of *Echinochloa colona* (L.) Link seeding, since the germinate at 0-1.5 cm soil depth (Vongsaroj and Notaya, 1991). Yingviwatanapong (1986) found that plowing a deepwater rice field with a three-disc plow to a depth of 3.0-12.5 cm reduced the occurrence *Eleocharis* turned up to the soil surface and were killed by drying. Control methods must lower the viabillty of weed seeds, or alternatively stimulate germination, so that control can easily be achieved (Vongsaroj, 1976). In the case of heavy infestation of wild rice, burning the rice straw after harvest gave good control (Vongsaroj, 1976). Puckridge et al., (1988) found that broadcasting pre-germinated rice seeds onto puddled soil reduced the wild rice population because the germination of wild rice seeds was inhibited in saturated soil. For wet seeded rice, a single plowing followed by puddling and leveling of the soil surface minimized weeds because the water lavel over the whole field could be controlled at a specific depth to prevent weed germination.

Rice crops Rice seed should be free of weed seed. In the Phillippines Rao and Moody that (1990) found that most rice seed was contaminated with weed seeds. Rice seed should be made free of weed seeds by winnowing, floating the rice seed, and cleaning the equipment used for land preparation and threshing before its use. Cultivars of rice that will have advantage in competition with weeds should be tall and have an extensive leaf display with many long, wide horizontally disposed leaves, to shade weeds, have early rapid root growth, and be free tillering. (Moody, 1979). Vongsaroj et al.,(1977b) compared 10 rice varieties in transplanted rice and found that tall rice cultivars namely Khaodokmali, Puangnak 16, Nanfmol 34, Leung Pratew 123 and Kaokaew had less weeds than short cultivars. Biswas et al. (1992) found that the upland rice data of plots of Hashikalmi had less weed weight than other cultivars (Table 2). Hassan et al., (1994) found that the rice cultivars Arabi, Sakha, UPK 82-1-7, Bala, IET 144 and Dular reduced barnyardgrass fresh weight by 92 to 96% while Giza 176 reduced weeds only by 5% (Table 2) because those cultivars release allelopathic substances to inhibit weed growth. Many rice cultivars (Table 3) controlled signalgrass, ducksalad and purple ammania 60-90% while Rexmont and Palmyra had zero control (Dillday, et al., 1990), and minimized *Cyperus difformis* L. (Table4) (Hassan, et al., 1994).

Table 1. Effect of upland rice cultivars on weed weight and percentage of light interception and grain yield (Biswas, Sattar and Bashar, 1992).

Entry	Rice plant no.	Weed wt.	Radiation interception (%)	Grain yield (kg/ha)
BR 4290-3-35	176	215 b	27.10	374 b
BR 4290-3-1-10	181	203 b	31.19	442 ab
IR 255-88-7-3-1	193	200 b	28.01	259 b
BR 20	130	225 b	29.64	357 b
BR 21	167	201 b	34.18	407 ab
Hashikalmi	296	132 a	36.37	647 a

In upland rice feilds, weeds and rice seeds germinate at the same time. Much upland rice cultivation is practiced in deforested areas where there are no weeds during the first year, but during the second and third years heavy weed infestations occur. There are no barriers to the spread of weeds from adjafdent clear areas, and intense of sunlight on the exposed soil induces the germination of weed seeds. The upland farmer solves this weed problems by moving on to a new site every few years.

Table 2. Allelopathic activity of different rice genotype on growth of barnyardgrass in the green house (Hassan, et al., 1994).

Rice genotype	Barnyardgrass (BYG) (plant height) cm	Barnyardgrass fresh wt. (g/pot)	% Reduction in BYG fresh wt.
Barnyardgrass	36.3	34.65	0
Giza 176	34.7	33.01	5
Arabi	23.8	2.65	92
Sakha-2	15.3	2.60	92
Ratna	19.5	1.34	96
UPR 82-1-7	15.5	1.48	96
Bala	8.3	1.50	96
IET 1444	6.5	1.49	96
Dular	8.1	1.50	96

Table 3. Rice germination accessions with potential allelopathic actvity to broadleaf signalgass, ducksalad, and purple ammania, 1988-1991. (Dilday et al. 1990).

Weed species	Germination designation	Country of origin	Radius (cm) of activity	Weed control (%)
Broadleaf	Daudzai	Pakistan	25.0	90
Signal grass	IR 329 19522	Phillippines	25.0	90
		Indonesia	25.0	80
		Japan	12.5	60
Ducksalad	AC 1423	India	17.8	85
	Tono Brea 439	Domican	16.5	85
	Tsai Yuan Chon	Taiwan	15.2	90
	Donduni Kunluz	Afghanistan	1.52	85
Purple ammania	IR 104456	Phillippines	17.5	77
	Cuba 65 V 58	United States	17.5	72
	Cuba 6558 A	United States	17.5	70
	IR 75 693	Phillippines	14.0	80
	IR 52 1673	Phillippines	14.0	80

Check cultivars (Rexmont and Palmyra) had zero allelopathic activity

Table 4 Allelopathic activity of different rice genotype on growth of *Cyperus difformis* in the greenhouse (Hassan, et al.,1994)

Rice genotype	Cyperus difformis	
	Fresh wt. (g/pot)	% Reduction
Cyperus difformis -Check	1.288 a	-
Giza 172-check	4.424 a	8
Giza 175-check	4.654 a	5
IR 2006-P 3-33-2	0.132 b	94
Kim Rad F 87	0.432 b	91
Dular	0.232 b	95

Method of Planting There are several types of rice cultivation upland rice, dry seeded rice, deepwater rice, transplanted rice and wet-seeded rice. The level of weed infestation varies with different methods of plamting. Upland rice has the worst weed infestation and transplanted rice has the least. Dry seeded rice and wet-seeded rice have intermediate weed infestation (Kittipong, 1983).

Water control Water is widely recognized as effective means of suppressing weeds. Flooding transplanted rice for 30 days suppresses weed growth (Publico and Moody, 1993.) Dry seeded rice is sown under dry conditions, but when the field is flooded, weeds at some growth stages are killed. Nakkaew et al, (1991) found that all *Echinochloa colona* plants were killed when the field was submerged for two weeks at a depth greater than 30 cm at 10 or 20 days after emergence farmers have a good stand of rice before they flood the field, most weed will be suppressed. In wet seeded rice, farmers drain water out 10 days after seeding. The population of *Echinochloa crus-galli* (L.) Beauv, *Cyperus difformis* (L.) will then be reduced under dry conditions, but be replaced by *Echinochloa colona* (L.) Link, *Leptochloa chinensis* (L.) Nees and *Ischaemum rugosum* Salisb. which are then partly killed when the field is flooded again. *Leptochloa chinensis* gradually (L.) Nees was completely controled by flooding 15-20 days after sowing (Drost and Moody, 1981). (Table 5). In irrigated areas, farmers grow wet-seeded rice as an upland crop to induce upland weeds to germinate. The land is gradually flooded from 5-10 days after crop emergence until flowering stage to a depth of 15-20 cm. This controls some weeds (Vongsaroj et al., 1977 a).

Transplanted rice Transplanting was introduced to minimize weed problems. Flooding at 5-10 cm depth after transplanting prevents germination of some weeds. Even if some weed species germinate under submerged condition, the height of the rice seedlings is 20-30 cm as the weeds just start to germinate. Rice has the advantage is competition with the weeds.

Direct seeded rice Direct seeding can be either dry seeded rice or wet seeded using pre-germinated seeds. Although transplanting does reduce weeds, it involves high production cost in terms of a nursery bed for seedlings, and the labour cost of gathering seedlings and hand transplanting. Wet seeded rice was developed in order to reduce costs (Kanchanomai, 1981). Both wet and dry direct seeded rice has weed problems, because rice and weeds germinate at the same time. After direct seeding has been used for a few years, it is recommended that farmers change temperarily to transplanting, which is particularly effeetive by controlling

Echinlochloa crus-galli (L.) Beauv. and *Leptochloa chinensis* (L.) Nees in the control plain of Thailand (Vongsaroj, 1987).

Plant density Seeding rate has an important role in weed control,. Farmers normally sow seeds in dense stands to help the rice compete with weeds. In dry seeded rice, a seed rate of 125-162.50 kg/ha was very effective in suppressing weeds. For wet seeded rice, a rate of 100 kg/ha was suitable to compete with weeds (Kanchanomai, 1981). In transplanted rice, spacing hills 25x25 cm with 1,3,6,9 and 15 plants/hill gave a dry weight of *Marsilea crenata* Presl of 197.60, 188.40, 108.00, 111.20, 120.80, or 114.80 g/sq.m) respectively (Supatakul and Khomvilai, 1986). Transplanting at spacing of 8x8 cm with one plant/hill minimized infestation by *Chara zeylanica* Willd. in the northeast of Thailand (Vongsaroj et al., 1977 a).

Table 5. Weed density and biomass of *Leptochloa chinensis* growing in association with wet-seeded rice as affect by time of floding (Drost and Moody, 1981).

Time of flooding (DS)	Weed density no/m^2	Weed wt. (g/m^2)
5	o a	0 a
10	2 a	0 a
15	42 b	25.0 b
20	72 b	25.0 b

Weed control Manual weeding be done is the primary direct weed control method and should be done at the early stages of rice growth. However it is labour intensive, and labour costs are rising with the alternative demands for labour both on and off farm. It is recommend that hand weeding of transplanted rice is carried out for the first time 20-30 days after transplanting. It should be carried out 20-30 days after seeding in case of upland rice, dry seeded rice and deepwater rice (Anon, 1988). Manual weeding can be replaced by rotary weeder or small machine, if it is available. Most farmers do hand weeding whenever they are free from other work. If weeding is delayed until the initiation of rice panicle primodia, the rice yield will be greatly reduced.

Judicious use of herbicides

Herbicides can eradicate hard to control weeds in a rotation ; more efficient use of land, reduce the need for cultivation;use as harvesting aid; maintain low weed seed number in the soil and increase efficiency of external production factors (Zoschke, 1994). All these increase rice yield and quality due to reduce competition. Herbicides also ease working conditions by minimizing hand labour, increase human effiency; promote pride in clean field; give more leisure times better education, and reduce costs, provide time for alternate weeding operations and maximize income and net profit (Zoschke, 1994). Herbicides have been introduced to control weeds and minimize the possible harzards to non-target organisma of all sorts from micro-organisms to mammals (Hance, 1990), Herbicides should only be used when really needed and must be applied at the right rate and right time. Butachlor, (Machete EC 60% a.i.) , propanil (Stam F EC 35 % a.i.) oxadiazon, (Ronstar EC 25 %) and thiobencarb + propanil (Saturnil) EC 60 % a.i.) at 0.8, 10.0-0.5, 3.0, 0.75 and 2.4-1.2 kg a.i./ha for weed control and higher yield respectively were most effective (IRRI, 1981).

Possibility of substitution Herbicides are widely used in paddyfields, but may be acutely or chronically toxic to other organisms, man included (Hance, 1990.) Substitution by other methods or materials is often desirable. For examples plant allelspathic substances that extracts of *Eupatorium adenophorum* Spreng. inhibited germination of 9 weed species e.g. *Amaranthus spinosus* L., *Amaranthus viridis* L., *Bidens pilosa* L. and *Borreria alata* DC. 90-100 % (Zungsontiporn and Premassthira, 1994). other bioagents for weed control was found, *Azolla* suppressed 69-100 % of weed in tranplanted rice (Janiya and Moody, 1984) and controlled *Monochoria vaginalis* in transplanted rice in Thailand (Table 6)(Vongsaroj et al., 1944). When combined with fish system , rice-azolla-fish minimized weed density and weed weight (Table 7) (Liu Chung - chu, 1987). For fish, Tubb (1961) reported that during early rice growth, a field containing milk fish (*Chanos chanos*) required less weeding than a field without fish. The water level should be 20 - 30 cm. Ducks were also found to minimize weed number and weed weight (Table 8) (Komson et al., 1995 ; Manda, 1992) and reduced red rice grain in U.S.A. (Smith, Jr. and Sullivan, 1980). Utilization of weeds in another mean of weed control, there are many weeds species are used as vegetable (Table 9) (Prachasaisoradcj, 1989; Jackquat and Bertussa) and *Marsilea crenata* in proved to have high nutritional value (Anon, 1992)

Carry over effectiveness of herbicides Oxadiazon and oxyfluorfen were used to control weeds in rice crop and after rice had been harvested, soybean was immediately planted in rice straw without any tillage. Weed control in rice crop had a residual effect on the soybean crop, reducing the incidence of broadleaf weeds (Vongsaroj and Price, 1987). The same had been results were found in 1992, 1993 and 1994 when growing soybean after rice which treated with pretilachlor (Kanchapan et al, 1995). Similar effects were found when soybean, mungbean and sunflower were grown after rice treated with thiobencarb, butachlor and piperophos/dimethametryn (Vongsaroj, 1993).

Table 6. Azolla and Lemna for control of some weeds in dry season (Vongsaroj;1994).

Treatment	Dry weight of weeds			Yield of rice t/ha
	1	2	3	
Azolla 62.5 kg/ha	3.72 b	1.2 b	2.7 ab	3.3 bc
Azolla 125.0 kg/ha	3.27 b	0.4 a	2.3 ab	3.9 a
Azolla 197.5 kg/ha	2.11 b	0.3 a	3.0 ab	3.9 a
Azolla 250 kg/ha	2.35 b	0.2 a	0.9 a	4.1 a
Lemna 62.5 kg/ha	0.62 ab	1.1 ab	2.5 ab	3.9 a
Lemna 125.0 kg/ha	0.37 a	0.1 ab	2.3 ab	3.7 b
Lemna 197.5 kg/ha	1.25 ab	0.3 a	2.7 ab	3.7 b
Lemna 250 kg/ha	0 a	0.5 a	1.5 a	3.7 b
Oxadiazon	0 a	0.3 a	0 a	3.9 a
Untreated check	8.08 c	1.5 b	7.5 c	3.1 c

1. 1 = *Cyperus difformis*
   2 = *Monochoria vaginalis*
   3 = *Sphenoclea zeylanica*
2. Values in the same column followed by the same letter are not significantly different at 5 % level by DMRT.

Table 7. The effect of rice-azolla-fish systems on weed growth. (Liu Chung-chu, 1987).

Treatment	Weed density no./m^2	Weed weight g/m^2
Rice	48.2	450
Rice-azolla	9.3	63
Rice-azolla-fish	1.8	11

Table 8. Frequency of duck agisting in the field as compared to hand weeding and chemical control at 8 weeks after transplanting (Komson et al., 1995).

Treatments	Height of rice plant (cm)	Number of rice tillers/hill	Dry weight of weeds (g/0.5 m^2)
Untreated check	84.1	25.9	19.8
Pretilachlor (Sofit EC 30 %)	84.6	28.8	18.4
Hand weeding	83.5	30.1	10.3
Duck agisting 1 time	83.3	27.1	22.5
Duck agisting 2 times	83.4	28.7	17.4
Duck agisting 3 times	82.8	30.9	15.6
Duck agisting 4 times	84.6	29.6	14.4
Duck agisting 5 times	83.5	29.4	9.4

Table 9. Edible weeds from paddy fields (Prachasaisorade, 1989; Jackquat and Bertussa, 1990).

Weeds	Family	Edilde parts of plant
Ceratopteris thalictroides Brown.	Parkeriaceae	Young fronds
Marsilea crenata Presl	Marsileaceae	Tender shoots and leaves
Nelumbo nucifera Gaertn	Nelumbonaceae	Young leaves
Nymphaea lotus Linn	Nymphaeaceae	Stalk of flowers
Nymphaea nouchali Burm.	Nymphaeaceae	Stalks of leaves
Jussiaea repens Linn	Onagraceae	Shoots and leaves
Crassocephalum crepidiodes S.	Compositae	Tuber
Moore	Compositae	Leaves
Spilanthes acmella Murr.	Convolvulaceae	Shoots young leaves,
Ipomoea aquatica Forsk		fruits
	Sphenocleaceae	Young plants
Sphenoclea zeylanica Gaertn.	Linnocharitaceae	Stalks of young leaves
Limnocharis flava Buch.	Hydrocharitaceae	Young leaves
Blyxa echinosperma Hook. F.	Hydrocharitaceae	Leaves
Blyxa japonica Maxim. Es Aschers		
+ Guerke.	Hydrocharitaceae	Young leaves
Ottelia alismoides Pers	Pontederiaceae	Young leaves
Monochoria hastata Solms	Pontederiaceae	Young shoots and
Monochoria vaginalis (Burm. f.)		leaves
	Aizoaceae	Young shoots, leaves
Mollugo pentaphylla Linn		and flowere
	Plantaginaeae	Young shoots
Plantago major Linn		

Environmental consideration weed control methods must pay attention to the user and the environment. Herbicides should not be toxic to human beings, e.g., 2,4,5-T, or to fish, eg., PCP in Japan,. Regulations should be set for the safe use or handling of herbicides in addition to those dealing with health and safety at work. Poisons and pollution are wider in scope and continue to have implication. Civil liabilities of the user of herbicide, employees, duty to neigbour, duty to public, contractor's duty to occupier and insurance should be set.

Economic and sustainability Cost of different methods of weed control treatments have different costs : hand weeding is labour consuming and wages are increasing year by year, and also difficult to get while herbicide cost is almost fixed. Vongsaroj, (1995) found that weed control treatments with herbicide application tended to have higher gross margin than hand weeding (Table 10). In the Phillippines a better return was obtained from weed control treatments (Table 11) (IRRI, 1981). If there is no risk for intergrated weed management, then technology will be sustained.

Table 10. Gross margin of weed control treatments in dry seeded rice in the north-east of Thailand (Vongsaroj , 1995).

Treatment	1990		1991	
	Yield of rice (t/ha)	Gross margin $	Yield of rice (t/ha)	Gross margin $
Weedy check	2.62 b	422	2.25 b	360
HW 30 DAE	2.63 b	383	2.66 ab	387
HW 45 DAE	2.66 a	485	3.18 a	411
HW 30+45 DAE	3.57 a	497	3.14 a	490
2,4-D	3.83 a	601	3.29 a	514
Propanil	3.78 a	568	3.51 a	526
2,4-D + HW 45 DAE	3.74 a	529	3.52 a	514
Propanil + HW 45 DAE	3.70 a	519	3.00 a	341
2,4-D + propanil	3.84 a	566	3.01 a	441
2,4-D + propanil + HW 45 DAE	3.70 a	511	3.59 a	433

Table 11 Return to weed control affected by weed control treatments (IRRI, 1981).

Treatment	Rate (kg a.i./ha)	Yield (t/ha)	Output ($)	Cost of weed control ($)	Return of weed control
Butachlor	0.8	3.1	508	12	414
Thiobencarb+2,4-D	1.0-0.5	2.6	426	19	325
Propanil	3.0	3.9	640	34	524
Oxadiazon	0.75	3.2	525	55	388
Thiobencarb+propanil	2.4-1.2	4.0	656	49	525
Unweeded	-	0.5	82	-	-

Replacement of labour Due to high wages and shortage of labour, replacement of labour should be attempted. No tillage systems, optimum plant population, models of water control, sheding rice cultivars, allelopathic subatances from rice cultivar or from weeds, biological control with available bio-agents in the coumtry and safe herbicides can be used. Small machines to hoe weeds must adopt planting methods with rice in rows.

Effect on crop production Crop production may be low from integrated weed management for sustainable rice production in the short term. It will get higher production if it is on practice for long term. When economic is concerned profits are high enough to adopt. In additonal with environment aspect, it will be far more benefit because weed control treatment are not harmful to the user and environment.

What is needed to continue The technique of growing rice has been changed from transplanting to wet seeded rice. Intergration of weed management for sustainable rice production must also be improved by researchers, but the real need is that technology must be easy to adopt, less input, maximum profit and not harmful to the environment, and conveniently implemented by farmers.

References

Annonymous. 1988. Guideline for weed control. Botany and weed Science Division, Department of Agriculture, Ministry of Agriculture and Copperatives. 66p.

Annonymous. 1992. Documentation of the Nutritional Division, Department of Hygiene, Ministry of Public Health.

Biswas, J.C., S.A. Sattar, and M.K. Bashar. 1992. Weed competitiveness of upland rice cultivars in Bangladesh. International Rice Research Newsletter 7 (3) : 14.

Dilday, R.H., R.E. Frans, N. Semidey, R.J. Smith. 1990. weed control with crop allelopathy. Arkansas Fram Research, 41 (4) : 14-15.

Drost, D.C. and K. Moody. 1981. Effect of weeding intensity on weed community compasition in rice (*Oryza sativa* L.) and upland crops grown in a rice field, bunded to pasequence. Saturday seminar, 28 February 1981. International Rice Research InStitute, Los Banos, Phillipines.

Hance, R.J. 1990. Ligislation and other safegards relating to the use of herbicides in U.K. Pages 521-540 in weed control Handbook: Principles (ed) Blackwell Scientific Publication.

Harwood, R.R. 1990. A history of sustainable in agriculture. Pages 3-19 in Edwards et al. (Eds.) Sustainable Agricultural Systems. Soil and Water Consortium Society, Ankeny, Iowa, U.S.A.

Hassan, S.M., Rao, A.N. Bastawisi, A.O. and I.R. aidy. 1994. Weed management in broadcast seeded rice in Egypt. International Workahop on Constraints, Oppotunities and Innovations for Wet-seeded Rice, 31 May-June 1994. Thailand.

IRRI. 1981. Annual Report. Internatinal Rice Research Institute. Los Banos, Phillippines.

Jackquat, C. and G Bertussa. 1990. Plants from the market of Tahiland. Doung Kamol, Bangkok. 251 p.

Janiya, J.D. and K. Moody. 1984. Use of *Azolla* to suppress weeds in transplanted rice. Tropical Peat Management 30 (1) : 1-6.

Kanchanapan, S.,P. Vongsaroj, V. Varamisara, J. Lekham, K. Nakorsri, and S. Sangvansa. 1995. Effect of herbicides applied in rice-soybean on weed density in rice-soybean pattern. Annual Report, Pitsanulok Rice Research Centre, Department of Agriculture.

Kanchanomai, P. 1981. Pre-germinated direct-seeded rice, new method of rice cultivation in Thailand. Department of Agriculture and cooperatives, 41 p.

Komson, N., P. Vongsaroj, and J. Lekham. 1985. Progress report on Efficacy of weed control with Khaki campbell ducks in transplanted rice. Botany and weed Science Division, Department of Agriculture, Bangkok, Thailand.

Kittipong, D. 1983. Weed control in Thailand. Proceedings of the Conference on Weed Control in Rice International Rice Research Institute, Los Banos, Phillippines. pp. 193-200.

Kon, K.F. 1993. Weed management : towards tomorrow. Proc 10th Australian and 14th Asain-Pacific Weed Conference Brisbane, Australia, September 1993, 1-9.

Liu Chung-chu, 1987. Rice-azolla-fish system. Paper presented at the International Rice Research Conference, 21-25 September 1987, Hangzhou, China.

Manda, M. 1992. Paddy rice cultivation using crossbred ducks. Farming Japan, 26 (4) : 35-42.

Moody, K., 1979. Exhibiting cultivar difference to improve weed control. Paper presented at the International Rice Research Conferences, 16-20 April, 1979. International Rice Research Institute, Los Banos, Phillippines.

Nakkaew, S., P. Nantasomsaran, A, Notaya, J, Lekham and P. Vongsaroj. 1991. *Echinochloa colona* (L.) Link under difference water depths. Annual Report, Botany and weed Science Division, Department of Agriculture, Thailand.

Prachasaisoradej, V. 1989. Edible plants in the North and North-east of Thailand, Botany and Weed Science Division, Department of Agriculture (unpublished data).

Publico, P.P. and K. Moody. 1983. Effect of follding duration on the performance of pretilachlor + fenclorium in wet-seeded rice and transplanted rice. Phillippines. J. Weed Sci. 20, 56-66.

Puckridge, D.W., L. Chankasem, P. Vongsaroj, P. Thongbai and B. Chinawong. 1988. Effect of tillage and sowing methods on control of wild rice. Proceedings of 1987 International Deepwater Rice Workshop. International Rice Research Institute, Los Banos, Phillippines. pp. 593-598.

Rao, A.N. and K. Moody. 1990. Weed seed contamination in rice seeds. Seed Sci. Technol., 18, 139-146.

Smith, R.J. Jr. 1993. Biological control as components of integrated weed management for rice in the United States. ASPEC Extension Bulletin p. 376-399.

Smith, R.J. Jr. and J.D. Sullivan. 1980. Reduction of res rice grain in rice fields by winter feeding of ducks. Arkansas Farm Research 29, 4:3.

Supatanakul, C. and C. Khomvilai. 1986. Influence of spacing on Marsilea crenata Presl competition in transplanted rice. Annual Report, Botany and weed Science Division, Department of Agriculture, Thailand 404 p.

Tubb, J.A. 1961. Anote on the cultivation of milkfish (chanos chanos) in rice field in Thailand. Int. Rice Comm. Newsl. 10 (2) : 3-4.

Vongsaroj, P. 1976. Wild rice at Prachin Buri province. Thai Journal of Weed Sci. 1 (2) : 20-23.

Vongsaroj, P. 1987. Weeds in paddy field and their control. Unpulished paper presented at the workshop at Cholburi procince. Arranged by the Department of Agricultureal Extension, Department of Technology and Economic Cooperation and Department of Agriculture, Thailand

Vongsaroj, P. 1995. Cost effective weed control methods for dry seeded rice in the North- east Thailand. Annual Report, Botany and weed Science Division, Department of Agriculture, Ministry of Agriculture and Cooperatives. 404 p.

Vongsaroj, P., A. Notaya. 1991. Report on work for Weed Science Group, Botany and weed Science Division, Department of Agriculture.

Vongsaroj, P. 1993. Effect of thiobencarb and piperophos/dimethametryn in transplanted rice on followed three crops and their weed. Thai Journal of Weed Sci. 2:35-48.

Vongsaroj, P. and C.E. Price. 1987. Weed control in rice-soybean ratation. Pages 549- 563. In Proceedings of the 11th Asain-Pacific Weed Science Society Conference, Taipei, Taiwan, ROC.

Vongsaroj, P. C. Suputanakul and T. Sangtong. 1977a. *Chara*. Technical Bulletin. Technical Divistion, Department of Agriculture.

Vongsaroj, p., J. Lekham, A. Notaya and J. Suktongsa. 1994. Efficacy of *Azlla pinnata, Lemna minor* at various rate on alternation control of weed to herbicide in transplanted rice.

Progress Report, Botany and weed Science Div, Department of Agriculture, Ministry of Agriculture and Cooperatives.

Vongsaroj, P., T. Sangtong, U. Chaimanit and A. Notaya. 1977 b. Study on competition between hybrid and native rice varieties in transplanted rice. Annual Report, Botany and Weed Science Divition, Department of Agriculture.

Yingiviwatanapong, Y. 1986. Effect of tillage practices on population of *Eleocharis dulcis* in abadoned paddyfield. Annual Report No. 1, botany and Weed Science Division, Department of Agriculture, Thailand. 404 p.

Zoschke, A. 1994. Toward rcduced herbicide rates and adapted weed management. Weed Tech., 8 (2) : 376-386.

Zungsontiporn, Z. and C. Premasthira. 1994. Effect of crude extract of *Eupatorium adenophorum* Spreng. on germination and growth of some crops and weeds Thai Agric. Res. Jour, 12 (1) : 37-41.

Sustainability in Rice Weed Management

Keith Moody
International Rice Research Institute
P.O. Box 933, Manila, Philippines

Abstract. For a number of years in Asia, there has been a problem of degradation of the environment and declining rice productivity in paddy fields. This has been accompanied by declining profitability and declining incomes from rice farming. In the future, there will be a need to greatly improve productivity while maintaining the sustainability of that increased productivity. The problem of sustaining productivity growth is caused by inadequate attention to understanding and responding to the physical, biological and ecological consequences of agricultural intensification. Intensification in rice production and changes in the methods of planting rice have resulted in changes in weed populations, emergence of new weed problems, including weedy forms of rice, and increased herbicide usage. There is increasing concern about the externalities of intensive rice production. Sustaining input use efficiency is closely related to understanding changes in the paddy system with intensification. Information will be required on the components of the weed flora, the effects of levels of weed infestation on crop performance and the efficacy and cost of potential means of control. Weeds have a strong impact on rice production and there are few practical alternatives to heavy reliance on tillage, high planting densities, water and herbicides for weed control. The challenge for weed research is to develop control strategies that maintain or enhance farm profits while safeguarding the environment and human health.

Introduction

As we look toward 2020 and beyond, the world must confront three central intertwined challenges: alleviating widespread poverty, meeting current and future food needs and managing the natural resource base to ensure sustainability. Compounding the difficulty of meeting these challenges is the expected addition of almost 100 million people to the world's population every year for the next 30 years and the limited availability of new land for cultivation in much of the world (Pinstrup-Andersen and Pandya-Lorch, 1994). The challenge is how to feed an increasing population without irreparably damaging the natural resource base on which agricultural production depends (Ehui and Hertel, 1989).

Rice, which is produced in a wide range of locations and under a variety of climatic conditions, is most closely associated with the south, southeast and east Asian nations extending from Pakistan to Japan. It is one of the most important crops in the world, providing 20% of global human per capita energy and 15% of per capita protein (IRRI, 1993).

For a number of years in Asia, there has been a problem of degradation of the environment and declining rice productivity in paddy fields. This has been accompanied by declining profitability and declining incomes from rice farming. In the future, there will be a need to greatly improve productivity while maintaining the sustainability of that increased productivity. The problem of sustaining productivity growth is caused by inadequate attention to understanding and responding to the physical, biological and ecological consequences of agricultural intensification (Pingali, 1991).

Intensification in rice production and changes in the method of planting rice have resulted in changes in weed populations, emergence of new weed problems, including weedy forms of rice, and increased herbicide use. There is increasing concern about the externalities of intensive rice production.

Problems

Undesirable weed shifts

The recent changes from transplanting to direct seeding of rice in Asia have resulted in dramatic changes in the types and intensity of weeds and their distribution. Studies conducted in Malaysia clearly show that direct seeding techniques cause weed populations to shift from less competitive broadleaved weeds to more problematical grasses. Weed surveys in the Muda area revealed that in the late 1970s when direct seeding was in the incipient stage of development (less than 1% of the planted area), there were 21 weed species belonging to 13 families. The hierarchical order of dominance was *Monochoria vaginalis* (Burm. f.) Presl > *Ludwigia hyssopifolia* (G. Don) Exell > *Fimbristylis miliacea* (L.) Vahl > *Cyperus difformis* L. > *Limnocharis flava* (L.) Buch. (Ho and Zuki, 1988). In the first season in 1989, when 82% of the area was direct seeded, 57 weed species belonging to 28 families were recorded. The order of severity was *Echinochloa crus-galli* (L.) P. Beauv. > *Leptochloa chinensis* (L.) Nees > *F. miliacea* > *Marsilea minuta* L. > *M. vaginalis* (Ho and Itoh, 1991).

Similar results have been observed in Korea. Kim (1992) reported a two- to three-fold increase in weed biomass and a shift in the dominant weed species to C_4 grass weeds in direct seeded rice compared to transplanted rice.

The continuous adoption of a particular practice inadvertently contributes to the shift in dominance and distribution of rice weeds. In the formulation of any weed management program, it is imperative that the recommended production practices be systematically manipulated and synchronized with the current location-specific farming activities. In this way, the most effective weed management is obtained (Ho *et al.*, 1994).

A program of weed control does not usually simply remove one species from within a community but will alter the relationships between the constituent species by disturbing the environment, altering competitive interactions or creating stress so disrupting the natural pattern of development change occurring in the community (Cook, 1990).

The use of herbicides moves the agroecosystem toward low species diversity which is contrary to the high species diversity of the natural ecosystem. Mahn and Helmecke (1979) stated that reliance on a single herbicide could result in quantitative changes in the structure of the weed population in as few as 5 years.

In Korea, since 1980, 140-150% of the irrigated rice area (100-120% of the total rice area) has been treated with herbicide annually. However, there has been too much reliance on a single herbicide. From 1975 to 1989, butachlor accounted for more than 50% of the total herbicide used, peaking in 1986 at 80%. This has resulted in undesirable weed shifts (Kim, 1994).

Increased herbicide use

The importance of weeds in rice production is likely to grow rather than diminish with continuing population-induced increases in land use intensity. The pressing need to raise yields and maintain profits on a progressively limited land base has paved the way for herbicide use in Asian rice production. Farmers are now left with little choice but to cut labor and production costs, particularly for the most labor-intensive tasks, such as planting and weeding. As a result, herbicides are being substituted widely for manual labor as a method of weed control. This trend has been reinforced by the spread of direct-seeded rice that requires chemical weed control in the early stages of crop growth to prevent substantial yield losses and by a decreasing ability in some systems to control weeds through water control as a consequence of diminishing water supplies and deteriorating irrigation structures (Naylor, 1994).

According to Woodburn (1993), it is realistic to expect that over the next 6 to 8 years, the average global expenditure on rice herbicides could exceed $10/ha compared to $7.50 at present resulting in an increase in the rice herbicide market in China and India from $67 million to over $550 million. Herbicides will represent the major growth area in the pesticide industry in the developing countries in the next decade.

The steady emergence of herbicides as a preferred technology for weed control in Asian rice systems follows a 20-year period of widespread growth in insecticide use that is just beginning to subside. Asian farmers now realize that their dependence on insecticides has often been unnecessary, expensive and sometimes even dangerous. Although herbicides are much less toxic and persistent than the majority of insecticides used in Asian rice production, the inevitable question arises: "Twenty years from now, will Asian societies regret having gone down the herbicide path?" (Naylor, 1994).

Weed resistance to herbicides

One important development as a result of continued use of the same herbicide is the evolution of weed species that have developed resistance to herbicides.

In Malaysia, a resistant form of *F. miliacea* has been found in rice fields where 2,4-D has been applied for 25 years; the weed cannot controlled with six times the recommended rate of 2,4-D (Watanabe *et al.*, 1994). Butachlor-resistant *E. crus-galli* has been reported in China (Huang and Lin, 1993). More resistance is observed where butachlor has been applied for 8-12 years and where two rice crops are grown per year.

Resistance is expected to become a much more serious economic problem within the next 5 to 10 years (LeBaron and McFarland, 1990). The problem can be avoided or reduced by exploiting a wide range of crop protection measures rather than over-relying on chemical inputs (Tan *et al.*, 1992).

Externalities

Despite the increasing use of herbicides in rice fields in south and southeast Asia, there is surprisingly little information on their external effects. Externalities have a value because people who can afford it are willing to pay for health and happiness, for clean water, fresh air and healthy food (Zadoks, 1992).

(a) Water. One of the main problems associated with the use of chemicals is to ensure that there is no pollution of water for its many uses. Caution must be used when applying herbicides in floodwater to avoid movement of the herbicide into groundwater or to keep treated water from contaminating other water as it drains from treated fields (Bayer, 1991).

In intensively cropped areas, agrochemicals are reaching shallow aquifers and contaminating groundwater. Castañeda and Bhuiyan (1995) reported that 24% of the groundwater samples collected from shallow tubewells within rice field boundaries were contaminated with butachlor, the maximum concentration in a single sample being 1.14 ppb. Present concentrations are much below dangerous levels but it is only a matter of time before toxic levels are reached. Studies are needed to understand the processes of agrochemical movement and contamination of the water resource base and to predict trends under alternative management options (Bhuiyan, pers. comm.).

(b) Health. In Malaysia, 51.3% of farmer respondents said that they had experienced symptoms associated with pesticide poisoning. The highest incidence (24.8%) was due to herbicides, mainly 2,4-D and paraquat. Headaches and dizziness were the most frequently mentioned symptoms. Drinking of coconut water was the main (73.6%, n = 120) remedial action. Only 12.8% consulted a medical doctor for treatment (Ho *et al.*, 1990).

Other factors

(a) Risk. Risk considerations can be important in determining farmers' choice of weed control methods and intensity of control in rice fields. Unlike other inputs such as water and fertilizers, weed control inputs are "protective" in the sense that they help reduce damage. Such inputs are generally considered to be "risk-reducing". Depending on the source of uncertainty, herbicides could be risk reducing or risk increasing (Pandey and Medd, 1991; Horowitz and Lichtenberg, 1994). To the extent they actually reduce risk, risk averse farmers would tend to apply more weed control inputs than risk neutral farmers.

Risk aversion could also be an important factor in determining the level of weed control inputs applied by rice farmers. Weed management practices which function effectively only under very precise conditions may be perceived to be too risky by farmers. For example, in the Mekong Delta in Vietnam, farmers do not like to use pretilachlor + fenclorim for weed control in wet-seeded rice because of the narrow application window (it has to be applied at 3-4 days after seeding). In the Philippines, farmers use low levels of weed control inputs even though the marginal benefit-cost ratio associated with high intensity weed control practices is large. In addition to credit constraints, such a behavior could be due to risk aversion.

(b) Economics. Herbicides are a highly productive input and the marginal return for every dollar invested in herbicides is strongly positive. This is consistent with increasing sales volumes of herbicides.

To the extent that herbicides are made cheaper relative to labor due to distortionary price policies, substitution of herbicides for labor is socially undesirable. In addition, negative environmental and health effects of herbicide use entail additional social costs.

The acceptability of more sustainable production systems is largely dependent upon success or failure in managing weeds. Assuming the development and successful implementation of novel agricultural systems that are biologically diverse and have reduced requirements for purchased inputs, economics will continue to dictate efficient weed management in the foreseeable future (Bridges, 1995).

Possible Solutions

Herbicide rate

Farmers in most countries in south and southeast Asia apply herbicides at less than the recommended rate (Navarez and Moody, 1979; Abeyratne *et al.*, 1984; van de Fliert and Matteson, 1990). In a number of experiments conducted at the International Rice Research Institute and in farmers' fields in the Philippines, application rates of preemergence herbicides, such as butachlor and pretilachlor + fenclorim, could be reduced by up to 50% of that recommended without loss in efficacy or reduction in crop yield (Mabbayad and Moody, 1985; Castin *et al.*, 1992; Pablico and Moody, 1993).

It is possible to reduce the recommended rate because it is often based on worst case situations for the most difficult to control weed species under unfavorable climatic conditions. However, the worst case approach is no longer acceptable. Instead, the rate should be adjusted to give exactly the required effect and no more under the prevailing conditions.

Amount of herbicide applied

The amount of herbicide applied can be reduced by using more effective herbicides applied at lower rates and by improving application equipment. Advances in application technology should reduce over application and drift and, therefore, reduce environmental contamination.

Recently developed herbicides that are applied at low rates and have low mammalian toxicity reduce the risk of environmental contamination. Application rates have been reduced from 1.8-3.0 kg/ha to 20-50 g/ha (Kim, 1994).

Appropriate herbicide selection is another way to reduce herbicide use. In many cases, in Korea, only one inexpensive herbicide application is needed (e.g., butachlor, thiobencarb or chlomethoxyfen for *Echinochloa* spp., *M. vaginalis* or other annual weeds; piperophos + dimethametryn for *Potamogeton distinctus* A. Benn.; and bentazon for *Eleocharis kuroguwai* Ohwi) rather than expensive and systematic applications of a number of herbicides (Kim, 1994).

Use postemergence herbicides

Postemergence herbicides are usually used at lower rates than preemergence herbicides and most have low to very low groundwater contamination potential (Worsham, 1991).

Risk considerations are important in the choice of preemergence versus postemergence herbicides. Preemergence herbicides have to be applied before weeds emerge; the application is prophylactic. On the other hand, postemergence herbicide use is more flexible because it can be tuned to the level of infestation. Farmers may, however, opt for prophylactic applications if they believe that postemergence control is too risky.

Crop rotation

Many weeds thrive best and cause the most trouble when the same crop is grown year after year. Some weeds are associated with certain crops or grow only in special habitats. Crop rotation or changing the habitat interferes with the normal life cycle of many weeds. Various systems of crop rotation have been employed from time to time. Many are useful for controlling weeds but the practicability of any specific method for a particular locality must be determined by considering such factors as climate, rainfall, suitability of soil, availability of markets and opportunity for utilizing or disposing of the crops. The success of a system of rotation, as far as the control of weeds is concerned, depends largely on the thoroughness and persistence with which the cultivated crop is kept free from weeds rather than on the kind of crop (Muenscher, 1960).

Allelopathy

Since plants are known to self-regulate their densities and distribution in nature through allelopathic interactions, attention is now being given to the possibility of exploiting this phenomenon to aid in placing crops in a more favorable competitive position over weeds (Worsham, 1989).

Dilday *et al.* (1991) reported that 347 accessions from the USDA/ARS rice germplasm collection exhibited allelopathic activity to *Heteranthera limosa* (Sw.) Willd. Lin *et al.* (1993) found that six allelopathic rice lines reduced the dry weight of aquatic weeds from 93 to 99% compared with Rexmont, a cultivar without allelopathic activity.

Fujii (1992) screened 189 rice cultivars for allelopathic activity, using lettuce as the assay crop, and found distinct differences between cultivars. Improved Japonica cultivars showed little allelopathic activity; traditional Javanica rice cultivars and red rice strains showed strong activity. The allelopathic activity of *Oryza glaberrima* Steud. was also strong.

Mulching

The phytotoxic potential of crop residues could be exploited in management of various weeds in agroecosystems. Dilday *et al.* (1992) reported that allelochemicals were present in straw of rice accessions that showed allelopathic activity in the field to *H. limosa*. Rice germplasm with high allelopathic activity combined with its straw incorporated into soil controlled *Cyperus iria* L. almost as effectively as a tank mixture of propanil + bentazon (Lin *et al.*, 1992).

Khan and Vaishya (1992) reported that residues of rice cv. Sarjoo-52 incorporated 5-6 cm deep at 5 t/ha reduced populations of *Echinochloa colona* (L.) Link and broadleaved weeds (*Ammannia baccifera* L., *A. multiflora* Roxb. and *Phyllanthus fraternus* Webster) by 40 and 56%, respectively and their biomass production by 39 and 64% whereas germination and biomass production of *Fimbristylis dichomata* (L.) Vahl and *F. ovata* (Burm. f.) Kern were stimulated.

Biological control

Augmentive biological control of weeds refers to the utilization of endemic natural enemies against endemic weed species or exotic weed species which were introduced long ago and have become naturalized in the present habitat. In the bioherbicide approach, excesses of pathogen inoculum are applied to the entire population of an indigenous weed in the same manner as chemical herbicides, causing infection and death of the contacted host plants.

Only one microbial herbicide, an endemic fungal pathogen, *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. *aeschynomene*, is registered for the control of a weed [*Aeschynomene virginica* (L.) B.S.P.] in rice in the United States. However, this product is no longer manufactured because it is too expensive.

Pathogens that have shown potential as biological control agents for controlling weeds in rice in Asia include *Drechslera monoceras* (Drechsler) Subram. & Jain for the control of *E. crus-galli* (Gohbara and Yamaguchi, 1992), *Epicoccosorus nematosporus* Yokoyama et Suzuki for the control of *E. kuroguwai* (Gohbara and Yamaguchi, 1992), and a leaf blight pathogen for the control of *Sphenoclea zeylanica* Gaertn. (Bayot *et al.*, 1992).

Although bioherbicides produce no environmental contamination or toxicity to humans, their selectivity can be a disadvantage because each agent controls only one weed species. Other problems include the difficulty of commercially producing and formulating the organism while maintaining its viability (Ho *et al.*, 1994). The use of naturally occurring enemies such as plant pathogens appears to offer an environmentally friendly natural solution to weed problems. In practice, however, there are many problems associated with their development and effective use that will probably prevent them becoming a significant method of weed control in arable crop production at least until the year 2000 (Williams, 1992).

Cover crops

The use of cover crops is increasing in popularity as farmers become more concerned with the need to reduce inputs and protect the quality of their farm environments. In addition to providing on-farm sources of nitrogen and organic matter, legumes may decrease soil erosion, improve soil physical characteristics, increase cropping system biodiversity and increase yields. Mallick (1981/82) reported that using *Sesbania bispinosa* (Jacq.) W.F. Wight as a green manure resulted in a reduction in weed growth.

The mechanisms of weed suppression by cover crops are complex. Cover crop residues can inhibit weeds through purely physical influences such as reduction in light or soil temperature. Living cover crops may interfere with weeds through competition for limited growth requisites. Allelopathic interference through the release of chemicals from plants or residues may also be involved (Hoffman and Weston, 1995).

Integrated weed control

Increasing herbicide use is likely to result in a move from integrated weed control to a "simple" weed control technology. Factors such as herbicide-resistant weeds, build-up of tolerant weed species and environmental contamination will result in greater integration of weed control practices. A balance between the two must be reached taking into consideration all the factors involved.

Weeds are most effectively controlled by the simultaneous application of a variety of practices, the total effect of which is usually greater than the effects of individual measures employed separately. Lower herbicide rates or better herbicide performance is achieved when optimum cultural practices are used.

Conclusions

Rice fields form a recurring part of the landscape of many countries and rice provides sustenance to more people than any other cereal. The wise use of rice fields is, therefore, a worthy objective (Fernando, 1980).

At present, there is no package of technology available to transfer to producers that can assure the sustainability of growth in agricultural production at a rate that will enable agriculture, particularly in the developing countries, to meet the demands being placed on them (Ruttan, 1988).

Growth of agricultural production is not incompatible with natural resource protection. The growth path must be based on technologies that do not exploit the resources and make maximal use of the biological potential (de Haen, 1991). The research agenda on sustainable agriculture needs to define what is biologically feasible without being excessively limited by present economic constraints (Ruttan, 1991).

Agriculture will be made more sustainable not by going back but by drawing on the best from the past and the best of modern technology (Fawcett, 1995). Sustainable agriculture supports a system of agriculture that over the long term, improves environmental resources such as soil and water, creates a healthful and plentiful food supply, is not harmful to farmer health and fosters a system of agriculture that is supportive of economically viable rural communities (Wyse, 1995).

The composition of weed communities of arable land are a reflection of the production and management practices imposed on the land. Trends towards reduced tillage, reduced herbicide use, intensified rotations, organic sources of nutrients and other changes in production practices change the environment where weeds are managed, compete and reproduce. Modifying crop management inputs will result in an altered competitive environment in which morphological and physiological traits that confer success will shift. These changes must be taken into consideration to develop economically and environmentally sound weed management systems (Buhler, 1995).

The importance of weeds in rice production is likely to grow rather than diminish with continuing population-induced increases in land use intensity. Rice weed control problems are compounded by growing water scarcities and by the rapid shift from transplanting to direct seeding. Herbicide use is expected to keep growing as farmers shift out of hand weeding in response to rising wage rates.

No single weed control technique is perfect and because the weed population constantly adapts to its physical environment, a multilateral approach is required to ensure sustainability. There is a need to find ways to reduce dependency on herbicides. New weed control strategies must be found to balance the use of herbicides with environmental protection and the production of food safe for human consumption.

References

Abeyratne F., J. Janssen, P. Naylor, C. O'Reilly, G. Parfait, C. Rader, L. Satorre and Suwandi. 1984. Farming system in the H3 Old Settlement Area of the Mahaweli Development Project, Sri Lanka. ICRA Bull. 17. Wageningen, The Netherlands. 51 p.

Bayer, D.E. 1991. Weed management. Pages 287-309 *in* B.S. Luh, ed., Rice production, Vol. I. 2nd ed. Van Nostrand Reinhold, New York, USA.

Bayot, R.G., A.K. Watson and K. Moody. 1992. Control of paddy weeds by plant pathogens in the Philippines. Pages 273-283 *in* Biological control and integrated management of paddy and aquatic weeds in Asia. National Agricultural Research Center, Tsukuba, Japan.

Bridges, D.C. 1995. An economic basis for weed management in alternative agricultural systems. Weed Abstr. 35:122.

Buhler, D.D. 1995. Weed population shifts in response to changing cropping practices. Weed Abstr. 35:120.

Castañeda, A.R. and S.I. Bhuiyan. 1995. Groundwater contamination by ricefield pesticides and some influencing factors. Paper presented at the 11th Annual Conference of the Federation of Crop Science Societies of the Philippines, 23-29 April 1995, Dumaguete City, Philippines.

Castin, E.M., P.P. Pablico and K. Moody. 1992. Effect of water overflowing from a herbicide-treated rice field on herbicide performance. Trop. Pest Manage. 38:30-35.

Cook, C.D.K. 1990. Origin, autecology, and spread of some of the world's most troublesome aquatic weeds. Pages 31-38 *in* A.H. Pieterse and K.J. Murphy, eds., Aquatic weeds. The ecology and management of nuisance aquatic vegetation. Oxford University Press, Oxford, U.K.

Dilday, R.H., P. Nastasi, J. Lin and R.J. Smith, Jr. 1991. Allelopathic activity of rice (*Oryza sativa* L.) against ducksalad [*Heteranthera limosa* (Sw.) Willd]. Pages 193-201 *in* J.D. Hanson, M.J. Shaffer, D.A. Ball and C.V. Cole, eds., Proceedings of the Symposium on Sustainable Agriculture for the Great Plains, ARS-89. United States Department of Agriculture Agricultural Research Service, Washington, D.C., USA.

Dilday, R.H., R.E. Frans, N. Semidey, R.J. Smith, Jr. and L.R. Oliver. 1992. Weed control with crop allelopathy. Arkansas Farm Res. 41(4):14-15.

Ehui, S.K. and T.W. Hertel. 1989. Deforestation and agricultural productivity in the Côte d'Ivoire. Am. J. Agric. Econ. 71:703-711.

Fawcett, R.S. 1995. Were the good old days of agriculture sustainable? WSSA Abstr. 35:39.

Fernando, C.H. 1980. Ricefield ecosystems: a synthesis. Pages 938-942 *in* J.I. Furtado, ed., Tropical ecology and development. Proceedings of the Vth International Symposium of Tropical Ecology. International Society of Tropical Ecology, Kuala Lumpur, Malaysia.

van de Fliert, E. and P.C. Matteson. 1990. Rice integrated pest control training needs identified through a farmer survey in Sri Lanka. J. Pl. Protect. Trop. 7:15-26.

Fujii, Y. 1992. The potential biological control of paddy weeds with allelopathy - allelopathic effect of some rice varieties. Pages 305-320 *in* Biological control and integrated management of paddy and aquatic weeds in Asia. National Agricultural Research Center, Tsukuba, Japan.

Gohbara, M. and K. Yamaguchi. 1992. Biological control agents for rice paddy weed management in Japan. Pages 353-366 *in* Biological control and integrated management of paddy and aquatic weeds in Asia. National Agricultural Research Center, Tsukuba, Japan.

de Haen, H. 1991. Environmental consequences of agricultural growth. Pages 31-47 *in* S.A. Vosti, T. Reardon and W. von Urff, eds., Agricultural sustainability, growth, and poverty alleviation: issues and policies. Deutsche Stiftung für internationale Entwicklung, Feldafing, Federal Republic of Germany and International Food Policy Research Institute, Washington, D.C., USA.

Ho, N.K. and Md. Zuki I. 1988. Weed population changes from transplanted to direct seeded rice in the Muda area. Pages 55- 78 *in* Y.M. Lam, A.W. Cheong and M. Azmi, eds., Proceedings of the National Seminar and Workshop on Rice Field Weed Management. Malaysian Agricultural Research and Development Institute and Malaysian Agricultural Chemicals Association, Penang, Malaysia.

Ho, N.K., B.O. Asna, A. Aznan and A. Rabirah. 1990. Herbicide usage and associated incidences of poisoning in the Muda area, Malaysia: a case study. Pages 321-333 *in* S.A. Lee and K.T. Kon, eds., Proceedings of the 3rd Tropical Weed Science Conference. Malaysian Plant Protection Society, Kuala Lumpur, Malaysia.

Ho, N.K. and K. Itoh. 1991. Changes of weed flora and their distribution in the Muda area. Paper presented at the 8th MADA/TARC Quarterly Meeting, 3 Nov 1991, Alor Setar, Malaysia.

Ho, N.K., K. Itoh and A.B. Othman. 1994. Weed management and changes in rice production practices. Pages 217-232 *in* P.S. Teng, K.L. Heong and K. Moody, eds., Rice pest science and management. International Rice Research Institute, Los Baños, Laguna, Philippines.

Hoffman, M.L. and L.A. Weston. 1995. Experimental methods theat describe the effects of cover crops on weed development in controlled environments. WSSA Abstr. 35:91.

Horowitz, J.K. and E. Lichtenberg. 1994. Risk-reducing and risk-increasing effects of pesticides. J. Agric. Econ. 45:82-89.

Huang, B.Q. and S.X. Lin. 1993. Study on the resistance of barnyardgrass to butachlor in paddy fields in China [in Chinese, English abstract]. J. South China Agric. Univ. 14:103-108.

IRRI (International Rice Research Institute). 1993. Rice Almanac (1993-1995). Los Baños, Laguna, Philippines. 142 p.

Khan, A.H. and R.D. Vaishya. 1992. Allelopathic effects of different crop residues on germination and growth of weeds. Pages 59-60 *in* P. Tauro and S.S. Narwal, eds., Proceedings 1st National Symposium Allelopathy in Agroecosystems. Indian Society of Allelopathy, Haryana Agricultural University, Hisar, India.

Kim, S.C. 1992. Weed ecology and effective weed control technology in direct-seeded rice [in Korean, English abstract]. Korean J. Weed Sci. 12:230-260.

Kim, S.C. 1994. Reduced herbicide use for weed control in irrigated rice in Korea. Pages 233-243 *in* P.S. Teng, K.L. Heong and K. Moody, eds., Rice pest science and management. International Rice Research Institute, Los Baños, Laguna, Philippines.

LeBaron, H.M. and J. McFarland. 1990. Overview and prognosis of herbicide resistance in weeds and crops. Pages 336-352 *in* M.B. Green, H.M. LeBaron and W.M. Moberg, eds., Managing resistance to agrochemicals: From fundamental research to practical strategies. ACS Symposium Series 421, Washington, D.C., USA.

Lin, J., R.J. Smith, Jr. and R.H. Dilday. 1992. Allelopathic activity of rice germplasm on weeds. Page 99 *in* Proceedings of the 45th Annual Meeting of the Southern Weed Science Society, Little Rock, Arkansas, USA.

Lin, J., R.J. Smith, Jr. and R.H. Dilday. 1993. Comparison of allelopathic rice and bensulfuron for aquatic weed control in rice. WSSA Abstr. 33:170.

Mabbayad, M.O. and K. Moody. 1985. Improving butachlor selectivity and weed control in wet-seeded rice. J. Plant Protect. Trop. 2:117-124.

Mahn, E.G. and K. Helmecke. 1979. Effects of herbicide treatment on the structure and functioning of agro-ecosystems. II. Structural changes in the plant community after the application of herbicides over several years. Agroecosystems 5:159-179.

Mallick, R.N. 1981/82. Rice in Nepal. Syndicate Printers, Jalandhar City, Nepal.

Muenscher, W.C. 1960. Weeds, 2nd ed. Macmillan, New York, USA. 560 p.

Navarez, D.C. and K. Moody. 1979. Farmers' weed control practices in rainfed lowland rice growing areas in Manaoag, Pangasinan, Philippines. Philipp. J. Weed Sci. 6:55-68.

Naylor, R. 1994. Herbicides in Asian rice production: perspectives from economics, ecology, and the agricultural sciences. Paper presented at a conference on Herbicide use in Asian rice production, 28-30 March 1994, Stanford University, California, USA.

Pablico, P.P. and K. Moody. 1993. Effect of flooding duration on the performance of pretilachlor + fenclorim in wet-seeded and transplanted rice. Philipp. J. Weed Sci. 20:56-61.

Pandey, S. and R.W. Medd. 1991. A stochastic dynamic programming framework for weed control decision making: an application to *Avena fatua* L. Agric. Econ. 6:115-128.

Pingali, P.L. 1991. Agricultural growth and the environment: conditions for their compatibility in Asia's humid tropics. Pages 295-310 *in* S.A. Vosti, T. Reardon and W. von Urff, eds., Agricultural sustainability, growth, and poverty alleviation: issues and policies. Deutsche Stiftung für internationale Entwicklung, Feldafing, Federal Republic of Germany and International Food Policy Research Institute, Washington, D.C., USA.

Pinstrup-Andersen, P. and R. Pandya-Lorch. 1994. Alleviating poverty, intensifying agriculture, and effectively managing natural resources. Food, Agriculture, and the Environment Discussion Paper 1. International Food Policy Research Institute, Washington, D.C., USA. 21 p.

Ruttan, V.W. 1988. Sustainability is not enough. Am. J. Alternative Agric. (Spring/Summer):128-130.

Ruttan, V.W. 1991. Sustainable growth in agricultural production: poetry, policy and science. Pages 13-28 *in* S.A. Vosti, T. Reardon and W. von Urff, eds., Agricultural sustainability, growth, and poverty alleviation: issues and policies. Deutsche Stiftung für internationale Entwicklung, Feldafing, Federal Republic of Germany and International Food Policy Research Institute, Washington, D.C., USA.

Tan, S.H., H.F. Yeoh, S. Ramasamy and A.M. Salleh. 1992. Pesticide use in Malaysia in the year 2000. Pages 165-174 *in* A.A.S.A. Kadir and H.S. Barlow, eds., Pest management and the environment in 2000. CAB International, Wallingford, Oxon, U.K.

Watanabe, H., I. Md. Zuki and N.K. Ho. 1994. 2,4-D resistance of *Fimbristylis miliacea* in direct seeded rice fields in the Muda area. Pages 353-356 *in* A. Rajan and Y. Ibrahim, eds., Proceedings of the 4th International Conference on Plant Protection in the Tropics, Kuala Lumpur, Malaysia.

Williams, R.J. 1992. Management of weeds in the year 2000. Pages 257-269 *in* A.A.S.A. Kadir and H.S. Barlow, eds., Pest management and the environment in 2000. CAB International, Wallingford, Oxon, United Kingdom.

Woodburn, A. 1993. Rice - the crop and its agrochemicals market. Allan Woodburn Associates Ltd., Midlothian, U.K./Managing Resources Ltd., Cambridge, U.K.

Worsham, A.D. 1989. Current and potential techniques using allelopathy as an aid in weed management. Pages 275-291 *in* C.H. Chou and G.R. Waller, eds., Phytochemical ecology: allelochemicals, mycotoxins, and insect pheromones and allomones. Monogr. Ser. 9, Institute of Botany, Academica Sinica, Taipei, China.

Worsham, A.D. 1991. Allelopathic cover crops to reduce herbicide input. Pages 58-69 *in* Proceedings of the 44th Annual Meeting of the Southern Weed Science Society, San Antonio, Texas, USA.

Wyse, D. 1995. Food quality: a component of sustainable agriculture. WSSA Abstr. 35:120.

Zadoks, J.C. 1992. The costs of change in plant protection. J. Pl. Protect. Trop. 9:151-159.

THE CONTRIBUTION OF NO-TILLAGE CROP PRODUCTION TO SUSTAINABLE AGRICULTURE

A. D. Worsham, G. G. Nagabhushana, and J. P. Yenish
Prof. Emeritus, Crop Sci. Dep., N.C. State
Univ., Upper Mt. Res. Stn., Laurel Springs, N.C.;
Post-Doc. Res. Assoc., Crop Sci. Dep., N.C.
State Univ., Raleigh, NC; and
Post-Doc. Res. Assoc., Dep. Agron. and Plant Genetics,
Univ. of Minnesota, St. Paul, MN, U.S.A.

Abstract. No matter how one may define sustainable agriculture, use of soil-conserving cropping practices, less synthetic herbicide inputs, and as good as or better weed control would be compatible components. Previously, these components have been considered to be incompatible by some, since it was widely believed that soil-conserving practices required increased pesticide use, including herbicides. However, we have shown that environmental and ecological differences between no-till and conventional tillage can enhance control of certain weed species in no-till cropping systems. We have shown that with proper choice and manipulation of cover crops and residues, it is often possible to reduce the number and/or amount of herbicides needed. Thus, in eliminating tillage, which restricts weed seeds to poor germination sites, by utilizing allelochemicals leaching from a killed cover crop, and using newer, more effective herbicides when needed, weed management in no-till has become much more effective.

In North Carolina, although results have been variable, we have grown soybean (*Glycine max* L.), tobacco (*Nicotiana tabaccum* L.), corn (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), and sunflower (*Helianthus annus* L.) in killed heavy mulches of rye, (*Secale cereale* L.) without herbicides, other than a non-selective one to kill the rye. Early-season control of broadleaf weeds such as sicklepod (*Cassia obtusifolia* L.) morningglory spp. (*Ipomoea* spp.) cocklebur (*Xanthium strumarium* L.) prickly sida (*Sida spinosa* L.) and pigweed spp. (*Amaranthus* spp.) has been 80 to 90%. Rye has been the most weed suppressing cover crop among several small grains and subterranean clover (*Trifolium subterraneum* L.) and crimson clover (*Trifolium incarnatum* L.) the most suppressive legumes. Currently in the Southeastern U.S., it appears that it will still be most practical to use a non-selective herbicide for cover crop kill and selective postemergence herbicides as needed for late-season weeds and especially for grasses and perennial weeds. This approach will still enhance agricultural sustainability because; (a) productive top-soil will be conserved, (b) herbicide use (especially preemergence herbicides) can be reduced, and (c) herbicides for cover crop kill and postemergence selective herbicides have little potential for environmental contamination.
Key Words: allelopathy, cover crops, environmental contamination, herbicide reduction, soil erosion, weed control

INTRODUCTION

By the year 2025, 83% of the expected global population of 8.5 billion will be living in developing countries. Agriculture has to meet the challenge of providing enough food and fiber. Major adjustments will be needed to increase food production in a sustainable way and enhance food security. One of the priorities identified in the United Nations Programme of Action, "Earth Summit Agenda 21" in 1992 to create a sustainable agriculture and rural development was land conservation and improved management of inputs (1). Since weed management is one of the largest inputs in agriculture, what is the relationship of weed management to sustainable agriculture?

In order to discuss weed management for sustainable agriculture, it would appear desirable to define "Sustainable Agriculture" and the position weed scientists have taken on this subject. Following is a portion of a position statement compiled by a committee within the Weed Science Society of America.

"Our present agricultural system provides the United States with an abundant, diversified, high-quality, reasonably priced food supply. However, agriculture is and always has been in a constant state of change where producers must overcome numerous constraints in crop production. A major biological constraint to crop production is weeds, with which the Weed Science Society of America

(WSSA) has been vitally concerned. To be sustainable, agriculture must be profitable; therefore, economical weed management will play a significant role in Sustainable Agriculture -----."

In agreement with this position, therefore, use of soil-conserving cropping practices, less synthetic herbicide inputs, and as good or better weed control would be compatible components of sustainable agriculture. Weed scientists and agriculturalists in the Asian-Pacific area would probably not disagree. Many agricultural workers, however, believe these components incompatible, since it has been widely thought that conservation tillage, especially with use of cover crops, requires increased pesticide use, including herbicides.

Most of the benefits of cover crops are well known. They provide wind and water erosion control, conserve soil moisture by reducing evaporation and increasing infiltration, increase organic matter, increase fertility by recycling nutrients, add nitrogen (if legumes), and improve soil structure. It is now known that certain cover crops can also improve weed control by increasing mulch and allelopathically suppressing weed growth. This can improve agricultural sustainability and environmental quality, especially in protection of surface and groundwater, by reducing, or eliminating in some cases, the need for preemergence herbicides.

The majority of row-crop acreage in the Southeastern U.S. is on Coastal Plain soils, an area described by the U.S. Environmental Protection Agency as having a high potential for leaching of pesticides into groundwater. Similar areas as to leaching potential exist in the corn-soybean region of the Midwest. The primary weed management system for the U.S.'s 1.2 million acres of corn is the preemergence application of a combination of atrazine and alachlor, making them the most widely used herbicides in the U.S. In preliminary surveys, detectable residues of both atrazine and alachlor have been found in a small percentage of water wells (25). Programs to lessen the potential for groundwater contamination from pesticides have already been established and others seem inevitable (33, 34). These programs may involve changes in use patterns, restrictions for certain areas or states, or canceling the registered uses for certain products. As examples, atrazine and atrazine-containing herbicides became restricted use products on September 1, 1990 because of groundwater concerns. Currently, the USEPA is reviewing triazine herbicides for possible further restrictions on use in the U.S. On October 24, 1990, the manufacturer of alachlor canceled its use in the state of Florida because the cost of required groundwater tests made further sales in that state unprofitable. I understand that some countries in the Asian-Pacific area also have groundwater pesticide concerns.

The Conservation Provisions of the U.S. 1985 Food Security Act (Farm Bill) encouraged owners of highly erodible, cropped land to have approved conservation plans fully implemented by January, 1995. One means of achieving compliance in the Southeast will be the increased use of no-till planting. Much greater use of cover crops will be required to meet conservation guidelines for soil protection at planting time (30% ground cover for most of the U.S., 50% in N.C.), (28). These provisions were strengthened in the 1990 Farm Bill and there will likely be stronger provisions for protecting the environment in the 1995 Farm Bill, including incentives to reduce pesticide use.

Recent developments in weed management for crops planted no-till into killed cover crops will be discussed in this paper. The suppression of broadleaf weeds by certain cover crop mulches, possible reasons for this, and the implications for improvement of agricultural sustainability and of environmental quality, especially groundwater quality, will be discussed.

WEED SUPPRESSION BY COVER CROPS

Herbicides will continue to be a key component in most integrated weed management systems in the foreseeable future. Some problems and potential problems, however, are receiving increasing attention and concern. Such problems include persistence in soil, contamination of the environment (especially ground water), crop injury, an increase in herbicide-resistant weeds, increased costs of discovering and developing new herbicides, enhanced soil biodegradation, and container disposal (29, 30).

Because of these problems and other potential ones, increased attention is being focused on alternative ways of controlling weeds. Allelopathic suppression of weeds as a possible alternative weed management strategy has received increased study in recent years. Many papers and reviews on cover crops used, allelochemicals identified or suspected, and the degrees of weed control obtained from mulches have been published (2,3,4,5,6,8,10,11,12,15,16,17,18,21,23,24,26,27,29,30,31,32).

From results of laboratory experiments and observations of farmers in Japan, Brazil, and the USA, 46 plants for summer cover crops and 54 plants for winter cover crops were selected by Fujii and Waller (7) for field tests for weed control. Some promising allelopathic plants were found.

RESULTS OF WORK IN NORTH CAROLINA

Our work in North Carolina over a number of years has indicated that leaving a small grain mulch and not tilling gives 75 to 80% early-season control of a number of annual broadleaf weeds (Table 1). Removing straw, tilling and replacing straw gives 60% control. Removing straw and not tilling gives 40 to 50% control and removing straw and tilling the soil, without herbicides, gives little to no control of these weeds (Table 2. It was concluded that not tilling accounted for some weed control, but having straw alone contributed even more. Not tilling plus having a straw mulch gave the highest degree of weed control (27).

Table 1. Effect of straw management and tillage on weed suppression in no-till planted crops in North Carolina.[a] (Worsham 27)

Straw and tillage treatment	% Control[b]	
	Rye mulch[c]	Wheat mulch[c]
Remove straw and till soil	9 a	30 a
Remove straw, no-tillage	43 b	50 b
Remove straw, till and replace	60 c	60 c
Leave straw, no-tillage	76 d	81 d

[a]Average results from research in corn, soybeans, sorghum, and tobacco, 1980-1986.
[b]Early-season ratings on redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), morningglory sp. (*Ipomea* spp.), prickly sida (*Sida spinosa* L.), and sicklepod (*Cassia obtusifolia* L.).
[c]Means within a column followed by the same letter are not significantly different as determined by Waller-Duncan T-test (K-ratio =100).

Table 2. The effects of mulch, tillage, and diphenamid on weed control in flue-cured tobacco at two locations in North Carolina.[a]

Treatment	Weed control[b]	
	Broadleaf[c]	Grass[d]
Tilled no herbicide	8 e	47 c
Tilled plus herbicide	52 d	67 bc
No-till, no herbicide	68 bc	71 abc
No-till plus herbicide	87 ab	94 a
No-till, rye mulch, no herbicide	79 bc	54 bc
No-till, rye mulch plus herbicide	97 a	80 ab

[a]Modified from Shilling et al. (19).
[b]Ratings taken four weeks after transplanting. Means within a column followed by the same letter are not significantly different as determined by Waller-Duncan T-test (K-ratio =100).
[c]Redroot pigweed, common lambsquarter, and common ragweed.
[d]Goosegrass [*Eleusine indica* (L.) *Gaertn.*] and large crabgrass (*Digitaria sanguinalis* L.).

Among five no-tillage systems studied by Shilling et al. (19) using desiccated small grains for weed suppression, rye generally provided the best broadleaf weed control (Table 3). Rye has also been particularly effective in studies by Putnam and DeFrank (16), Barnes et al. (3), and Worsham (26). The high biomass production of shoots and roots, winter hardiness, and phytotoxicity of the residues make this grass crop very effective in no-tillage soil conservation cropping systems.

Table 3. Effects of Small Grain Mulch and Tillage on Weed Control at Two Locations Over Two Years in North Carolina.[a]

Mulch type[b]	% Weed control[d]	
	Broadleaf[e]	Grass[f]
Rye	85 ab	70 b
Wheat	74 c	61 bc
Barley	75 c	54 bc
Oats	80 bc	64 b
None	63 d	41 d
None[c]	90 a	81 a

[a]Modified from Shilling et al. (19).
[b]All treatments had 6.7 lb/A diphenamid and 3.3 kg/ha glyphosate applied to kill grain and provide residual weed control.
[c]Tilled and rebedded prior to transplanting tobacco and cultivated twice.
[d]Means within a column followed by the same letter are not significantly different as determined by Waller-Duncan T-test (K-ratio = 100). Ratings are in early-season; about 4 weeks after transplanting.
[e]Redroot pigweed, common lambsquarters, and common ragweed.
[f]Large crabgrass and goosegrass.

Shilling et al. (19) reported research in which they attempted to partition the weed control effects from tillage alone, no-tillage, and no-tillage plus mulch with and without a preemergence herbicide in tobacco (Table 2). Tillage alone without herbicide gave 8% early-season control of broadleaf weeds and 47% control of annual grasses. Adding a soil-applied herbicide gave 52 and 67% control of broadleaf weeds and grasses, respectively. Not tilling, without herbicide or mulch, gave 68 and 71% control. The no-till treatment without mulch plus herbicide yielded 87 and 94% control. Rye mulch alone, no-till without herbicide gave 79 and 54% control, respectively, of broadleaf and grass weeds and rye mulch plus herbicide in no-till gave 97 and 80% control. Results from the same treatments with wheat, oats (*Avena sativa* L.) and barley (*Hordeum vulgure* L.) were similar. These results confirm the need for not tilling plus having a mulch to achieve the highest degree of weed control without a preemergence herbicide.

In a study in 1989 to determine the difference in weed suppressing ability of a number of rye cultivars, after rye kill, no additional herbicides were needed for weed control in no-till corn, soybean, or grain sorghum. In 1990, however, weed control from the rye mulch alone was not adequate (8).

In a preliminary study in 1990, redroot pigweed (*Amaranthus retroflexus* L.) control four weeks after planting no-till corn, cotton, soybeans, or tobacco was 81% in rye, 79& in subterranean clover, 72% in crimson clover, 41% in hairy vetch, 39% in no cover no-till, and 0 in conventionally tilled plots. No preemergence or postemergence herbicides were used. Postemergence herbicides were needed later in the season for complete weed control for most crops (29).

Weed control by rye, crimson clover, subterranean clover, and hairy vetch (*Vicia villosa* Roth.) cover crops was evaluated in no-tillage corn and cotton (*Gossypium hirsutum* L.) during 1992 and 1993 (31). Conventional tillage and no-cover, no-tillage treatments were included for comparison. Rye, crimson clover, and subterranean clover gave the best weed suppression. Although some of the cover crops gave significant early-season weed control, they did not entirely replace herbicides. Additions of preemergence and/or postemergence herbicides with the mulches gave the highest crop yields, particularly in cotton.

Table 4. Early-season weed control in corn from cover-crop/tillage systems and PRE herbicides. Clayton and Rocky Mt., NC, 1992.[a]

Cover/crop Tillage system	Broadleaf weeds[b] PRE[c]	Broadleaf weeds[b] UTC[c]	Grasses[b] PRE	Grasses[b] UTC
	%			
Rye/no-till	97a	87b	95ab	84b
Crimson clover/no-till	98a	65c	94b	64c
Sub. clover/no-till	99a	82b	97a	72c
Hairy vetch/no-till	98a	42d	94b	42d
No cover/no-till	98a	23e	98ab	24e
No cover/conv. till	96a	0f	92a	0f

[a]Adapted from Yenish (31).
[b]Means within a type of weed followed by the same letter are not different at $P \leq 0.05$ according to Fisher's Protected LSD test of arsine transformed data. Data recorded 45 days after planting.
[c]PRE = 1.4 kg/ha atrazine + 2.2 kg/ha metolachlor applied preemergence. UTC = check without herbicide.

There is more recent evidence, however, that a cover crop can be manipulated to achieve greater weed control in the subsequently planted no-till crop. We found that increasing the seeding rate of rye, using a cultivar that tended to produce higher biomass, and killing the cover crop as close to planting time as possible all increased weed suppression. A very thick surface mulch provided adequate weed suppression for up to 10 weeks after transplanting tobacco (13).

Table 5. Effect of rye seeding rate on mulch and weed biomass. Reidsville, NC 1994[a].

Seeding rate Kg/ha	Rye biomass g/m^2	Biomass Grass weeds	Biomass Broadleaved weeds
0	0	5.2	81.9
67	225	4.2	12.1
134	244	13.9	15.3
202	285	2.0	2.6

[a]Preliminary data from Nagabhushana et al. (13). Data taken 45 days after planting.

In efforts to partition weed suppression effects between physical barriers of cover crops and allelopathy, we found that the duration of weed suppression by rye cover crops more closely followed disappearance of certain allelochemicals (DIBOA, DIBOA-glucoside, and BOA) from rye residue than disappearance of the residue itself (32). Published estimations of weed suppression duration also more closely follow disappearance of BIBOA-glucoside and related compounds from rye residue than disappearance of the residue (3,4,20).

IMPLICATIONS OF ALLELOPATHIC COVER CROPS IN NO-TILLAGE FOR SUSTAINABLE AGRICULTURE

As described in this paper, many cover crops temporarily suppress annual broadleaf weeds and there is evidence that this suppression in some cases may eliminate the need for preemergence soil-applied herbicides at time of planting summer crops. This has several benefits compatible with aims of sustainable agriculture. First, the cost of extra herbicide application is eliminated. The potential for groundwater contamination is lessened because herbicides used to kill the cover crops are foliar applied and do not leach in soil. Postemergence herbicides will probably still be required for most crops, but these, if needed, are usually used at much lower rates than preemergence herbicides, less will reach the soil, and most have low to very low ground water contamination potential according to the ranking index by Weber (22).

A method of evaluating groundwater contamination potential by changing to a postemergence weed management approach was given by Hoag (9) for soybeans. Using his "cost-environmental hazard predictive model", changing from the most herbicide-intensive, environmentally risky system to an environmentally desirable postemergence herbicide only, the groundwater risk potential was reduced by 65% at no extra cost to the producer. Further risk reduction was possible at very little cost. The new selective postemergence herbicides for corn should allow great reduction in environmental risk and groundwater contamination potential for this major acreage crop also.

The other well-known properties of cover crops that benefit the environment and sustainable agriculture such as wind and water soil erosion control, nutrient recycling, conserving soil moisture, increasing soil fertility and structure etc., would still be available with any allelopathic cover crops. There are disadvantages and potential problems, however, with the use of cover crops. Some of these are: cost of establishing, difficulty in killing (especially legumes), leaching of nitrates (if legumes), lowering of soil temperatures in spring, depletion of soil moisture in the spring, the unknown effects of releasing natural phytotoxins into the environment, and possible increase of certain insects and diseases.

Fujii and Waller (7) concluded that the use of living mulches as well as mixed plantings are necessary to develop a profitable, sustainable agriculture. Narwal (14) reported that in the near future, allelopathy-mediated weed control technology may be available which will be free from environmental pollution and suitable for future sustainability of agriculture.

More research is needed on the extent to which use of cover crops allelopathic to weeds can be substituted for herbicides. More research is especially needed to determine the factors influencing degree of weed suppression as results are variable now. Finally, more research would have to be done to provide the information needed to help growers integrate these new practices into on-going crop production practices and rotations.

LITERATURE CITED

1. Anonymous. 1992. Promoting sustainable agriculture and rural development. Pages 114-130 in Earth Summit Agenda 21, United Nations Conference on Environment and Development, June 1992, Rio de Janeiro, Brazil, U.N. Dept. of Public Info., Publication No . E. 93.1.11.
2. Barnes, J. P. and A. R. Putnam. 1986. Evidence for allelopathy by residues and aqueous extracts of rye (*Secale cereale*). Weed Sci. 34:384-390.
3. Barnes, J. P., A. R. Putnam, and A. Burke. 1986. Allelopathic activity of rye (*Secale cereale*). Pages 271-286 in A. R. Putnam and C. S. Tang, eds. The Science of Allelopathy. John Wiley and Sons, New York.
4. Doll, J. D. and T. Bauer. 1991. Rye: a double-barreled weed management tool. Proc. 1991 Wisc. Fert. Ag-lime Pest. Manage. Conf. 30:205-213.
5. Einhellig, F. A. and G. R. Leather. 1988. Potential for exploiting allelopathy to enhance crop production. J. Chem. Ecol. 14:1829-1844.
6. Enache, A. J. and R. D. Ilnicki. 1990. Weed control by subterranean clover (*Trifolium subterraneum*) used as a living mulch. Weed Technol. 4:534-538.
7. Fujii, Y. and G. R. Waller. 1994. Allelopathy of cover crops and their application to sustainable agriculture. Page 158 in Allelopathy in Sustainable Agriculture, Forestry, and Environment. Eds. S. S. Narwal and P. Tauro, Indian Soc. of Allelopathy, CCS Haryana Agric. Univ. Hisar, India.
8. Hinen, J. A. and A. D. Worsham. 1990. Evaluation of rye varieties for weed suppression in no-till corn. Page 49. In J. P. Mueller and M. G. Wagger. Eds. "Conservation Tillage for Agriculture in the 1990's." Proc. Sou. Reg. Cons. Tillage Conf., N.C. State Univ., Spec. Bull. 90-1.
9. Hoag, D. L. 1990. Reducing Agrichemical Risk in a Competitive Market System. Invited paper in "Agricultural Chemicals and Water Quality: Integration of Physical Sciences and Economics," annual meeting Amer. Assoc. Adv. of Science. 20 pages.
10. Johnson, G. A., M. S. Defelice, and Z. R. Helsel. 1993. Cover crop management and weed control in corn (*Zea mays).* Weed Technol. 7:425-430.

11. Liebl. R. A. and A. D. Worsham. 1983. Inhibition of pitted moringglory (*Ipomoea lacunosa* L.) and certain other weed species by phytotoxic components of wheat (*Triticum aestivum* L.) straw. J. Chem. Ecol. 9:1027-1043.
12. Liebl, R., F. W. Simmons, L. M. Wax, and E. W. Stoller. 1992. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean (*Glycine max*). Weed Technol. 6:838-846.
13. Nagabhushana, G. G., A. D. Worsham, F. H. Yelverton, W. B. Wickliffe, and R. W. Lemons. 1995. Agronomic manipulation of rye cover for improved weed suppression in no-till crop production systems. Proc. South. Weed. Sci. Soc. 48:(In Press).
14. Narwal, S. S. 1994. Potentials and prospects of allelopathy mediated weed control for sustainable agriculture and reducing environmental pollution. Page 161 in Allelopathy in Sustainable Agriculture, Forestry and Environment. Eds. S. S. Narwal and P. Tauro, Indian Soc. of Allelopathy, CCS Haryana Agric. Univ., Hisar, India.
15. Putnam, A. R. 1988. Allelopathy: problems and opportunities in weed management. In "Weed Management in Agroecosystems: Ecological Approaches" (Altieri, M. A. and Liebman, M., Eds.) CRC Press, Inc., Boca Raton, FL. pp. 77-88.
16. Putnam, A. R. and J. De Frank. 1983. Use of phytotoxic plant residues for selective weed control. Crop Protection 2:173-181.
17. Shilling, D. G., R. A. Liebl, and A. D. Worsham. 1985. Rye (*Secale cerale* L.) and wheat (*Triticum aestivum* L.) mulch: The suppression of certain broadleaved weeds and the isolation and identification of phytotoxins. In A. C. Thompson (Ed.) The Chemistry of Allelopathy: Biochemical Interactions Among Plants. ACS Symps. Ser. 268. American Chemical Society Washington D.C. pp. 243-271.
18. Shilling, D. G., L. A. Jones, A. D. Worsham, C. E. Parker and R. F. Wilson. 1986a. Isolation and identification of some phytotoxic compounds from aqueous extracts of rye (*Secale cereale* L.) J. Agric. Food Chem. 34:633-638.
19. Shilling, D. G., A. D. Worsham, and D. A. Danehower. 1986b. Influence of mulch, tillage, and diphenamid on weed control, yield, and quality in no-till flue-cured tobacco (*Nicotiana tabacum*). Weed Sci. 34:738-744.
20. Teasdale, J. R. 1993. Interaction of light, soil moisture, and temperature with weed suppression by hairy vetch residue. Weed Sci. 41:46-51.
21. Teasdale, J. R. 1993. Reduced-herbicide weed management systems for no-tillage corn (*Zea mays*) in a hairy vetch (*Vicia villosa*) cover crop. Weed Technol. 7:879-883.
22. Weber, J. B. 1990. Potential problems for North Carolina groundwater from herbicides: A ranking index. Proc. Weed Sci. Soc. of N.C. 8:30-46.
23. Weston, L. A., R. Harmon, and S. Mueller. 1989. Allelopathic potential of sorghum-sudangrass hybrid (Sudex). J. Chem. Ecol. 15:1855-1865.
24. White, R. H., A. D. Worsham, and U. Blum. 1989. Allelopathic potential of legume debris and aqueous extracts. Weed Sci. 37:674-679.
25. Williams, W., P. Holden, D. Parsons and M. Corber. 1988. Pesticides in Groundwater Data Base: 1988 Interim Report. EPA, Office of Pesticide Programs, Washington, D.C.
26. Worsham, A. D. 1984. Crop residues kill weeds: allelopathy at work with wheat and rye. Crops Soils 37:18-20.
27. Worsham, A. D. 1989. Current and potential techniques using allelopathy as an aid in weed management. Pages 275-291 in C. H. Chou and G. R. Waller, eds. Phytochemical Ecology: Allelochemicals, Mycotoxins and Insect Pheromones. Inst. of Botany, Academia Sinica Monograph Ser. No. 9, Taipei, ROC.
28. Worsham, A. D. 1990. Weed Management Stratagies for Conservation Tillage in the 1990's. Pages 42-47. In J. P. Mueller and M. G. Wagger, Eds. "Conservation Tillage for Agriculture in the 1990's". Proc. 1990. Sou. Reg. Cons. Tillage Conf., N.C. State Univ. Spec. Bull. 90-1.
29. Worsham, A. D. 1991. Allelopathic cover crops to reduce herbicide input. Proc. South. Weed Sci. Soc. 44:58-69.
30. Worsham, A. D. and U. Blum. 1992. Allelopathic cover crops to reduce herbicide inputs in cropping systems. Proc. of First Int. Weed Cont. Cong. 2:577-579.
31. Yenish, J. P. 1994. Weed suppression using allelopathic cover crops in no-tillage agriculture in North Carolina. Ph.D. diss., Crop Sci. Dept., N.C. State Univ., 85 pp.
32. Yenish, J. P., A. D. Worsham, and W. S. Chilton. 1995. Disappearance of DIBOA-glucoside, DIBOA, and BOA from rye (*Secale cereale* L.) cover crop residue. Weed Sci. 43:18-20.

33. Zinn, J. and M. Tieman. Groundwater Quality: Current Federal Programs and Recent Congressional Activities, CRS Report for Congress, No. 89-195 ENR, Congressional Research Service, Washington, DC. 1989.
34. Zinn, J. Omnibus Conservation Proposals for a 1990 Farm Bill: Background and Comparison. CRS Report for Congress, No. 89-441 ENR, Congressional Research Service, Washington, DC, 1989.

WEED MANAGEMENT ON A RUBBER PLANTATION WITH SPECIAL REFERENCE TO MINIMUM TILLAGE CULTIVATION

by
Soekisman Tjitrosemito, PhD.
SEAMEO BIOTROP P O Box 116 Bogor 16001

ABSTRACT

The establishment of perennial plantations is a process of vegetational succession. The succession will favour the development of "weeds" as considerable resources have been utilized by the almost unlimited number of weeds, compared to only about 500 plant lets/ha; therefore, weed control or vegetation management is necessary to direct the succession into vegetational domination of a good perennial plantation.

Problems of weeds exist in every stage of crop establishment, from pre-planting, nursery, immature, and mature rubber fields; it is therefore imperative that weed management strategies/ activities address the problem.

Crop establishment using minimum tillage cultivation will necessitates the classification of types of vegetation into those which are useful (A) and whose growth should be encouraged, those which are harmless (B), those which are useful soil cover as soft grasses (C), those that should be controlled (D), and those which should be eradicated (D).

Weed control activities are directed only toward certain species of weeds, leaving others to grow to be manipulated for the benefit of the plantation.

INTRODUCTION

Weed management, especially in perennial crop is more of vegetation management, i.e. a system of planned and responsive activities to promote the establishment of perennial crops by directing the process of vegetational succession from undesirable coarse of development toward a desirable one, i.e. vegetation in the area is dominated by rubber at the shortest possible period. It is understood from the outset that the condition immediately before or after manipulation is not usually the desired one and that through the anticipation of vegetation succession we set up vegetation communities to grow into a desirable form. Thus, a given manipulation of vegetation has an intermediate objective the appearance of a limited number of crop that will develop into a stand that we deem desirable (Miles, 1979).

The development of vegetational succession in perennial plantations is dependent upon physico-chemical and biotic factors such as stability of vegetation community before the establishment of perennial crops, edaphic as well as climatic suitability to introduced crops, abundance of other vegetations and juvenile growth habit of the crops, (Newton, 1981).

The conditional requirement that the rubber plants domination should occur at the shortest possible time., implies a set of activities which should be programmed and executed to direct the process of succession toward the domination of rubber plantation in the form of healthy rubber plantation.

The planned and responsive activities will cover various subject matters, such as :

(i) those related to pre-planting
(ii) those related to nursery
(iii) those related to rubber field

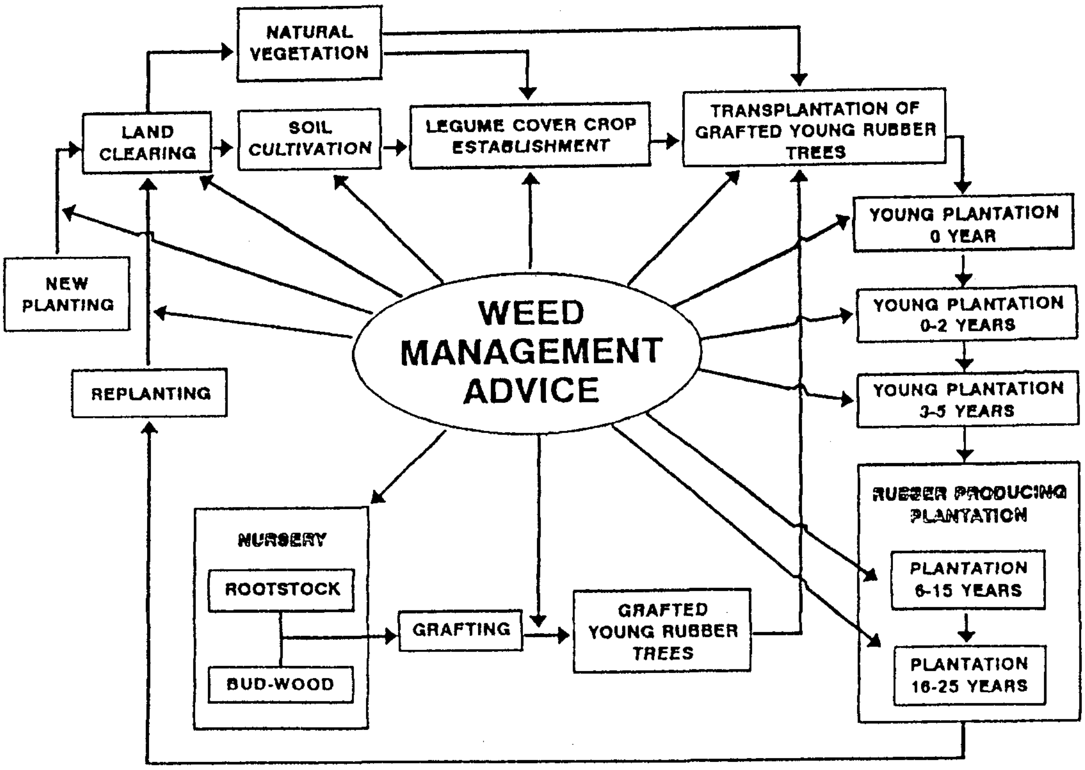


Figure 1. Diagram showing the relationship of various activities and points where weed management advises is required (Tjitrosemito and Mawardi, 1993)

PREPLANTING

A. Field Preparation

The first problem faced by plantation manager at the pre planting stage is stability of the existing vegetation community. Stability, in the ecological sense, is the resistance to change in composition. There is a trends for plant communities to become more stable as they increase in age. With increasing degree of site occupation, there is a decreasing chance for the establishment of immigrant seedlings (Odum, 1969; Eussen, 1981). Abundant recruitment of new plants tends to occur **only** after a substantial disturbance (Miles, 1979; Nearing & Goodwin, 1976). Therefore, if a community has stabilized in an undesirable stable state it must be disturbed to dislodge it, we are thus left with the basic principle that stability is natural property of plant communities and that disturbance of some kind is a pre requisite for a change in a trend of successional development. A logical corollary of this principle is that the need for intensive disturbance increases as successional stages mature.

The planning of field lay out has a strong bearing on weed control and management during preparation, planting, even for tapping. The size of unit fields with the accompanying road and drainage systems is very important factor to be considered seriously.

The areas for planting are differentiated into :
(a) Forested land
(b) Imperata land, and
(c) Old plantation

1. Forested land

Forested land refers to primary and secondary forests. The primary forest consists of trees with three or four storeys. The top storey is scattered, not forming a continuous cover but emerging here and there out of very large, buttressed trees over 50-70 m. The lower storey occurs at 30-50 m. Below the mature tree storey there is a large of young sapling trees, and below this is scanty undergrowth (Jacobs, 1988; Budowsler, 1965). In secondary forest, their undergrowth is much more abundant, although the population of trees is less but the methods used for clearing of these forests differ little.

Plant nutrients in a forest system are held in vegetation and the surface soil, and the good structure of the humic topsoil is protected from the impact of rainfall and sunlight by the closed forest canopy and by the deposited litter so that rainfall readily infiltrates into the soil. The destruction of stability for crop establishment should also consider this aspect. When the land is cleared and the bare soil is exposed to the sun and to the impact of rainfall, the decomposition of soil organic matter will be accelerated, leading to nutritional leachage, breakdown of the aggregate structure of the surface soil and erosion of the nutrient-rich soil surface. To avoid these ill effect as far as possible, the exposure of the bare soil should disturb and compact the soil as little as possible (Webster & Baulkwill, 1989).

The availability of land for establishing rubber plantation is decreasing, flat land has been utilized for expanding food crop production as some areas previously for food production have been converted to residential area and also factories in the process of urbanization.

Therefore, the accepted area for the establishment of rubber plantation, has been extended to lands having slope of 45°; Lands having slope more than 45° should not be considered for establishing rubber or other plantation but continuous cover. However, whenever sloping lands are utilized for plantation, necessary water and soil conservation works should be constructed.

The land clearing may be carried out by the following sequences:

a) Cut all undergrowth with "parang", fell trees with chainshaws, smaller first close to the ground, bigger ones 0.5-1.5 m above ground, but tressed trees 2.0 m above ground; uproot stumps. It requires 150-200 mwd/ha (man working days) for 200 trees/ha or when using bulldozers it requires 5 twh/ha.
b) Line felled trees in one direction parallel to the intended rubber rows and these activities are normally done in March-April (i.e. at the end of wet season).
c) Leave unsaleable materials to dry out by stacking and windrowing before burning in July - August.
d) Remove stumps, roots and other debris prior.
e) Construct the necessary soil conservation device, drainage and road systems.

Up to this point, if the area is formerly primary forest the weed infestation is not much, but in the secondary forest shrubs can be considerable, and these shrubs together with robust, big grasses (*Themeda* sp., *Saccharum* sp., *Imperata cylindrica*) should be eradicated before legume cover crops are planted.

2. *Imperata* land

The land slope requirement is the same as those of forested land. Generally works on land clearing under *Imperata* are much easier than those under forested land. Imperata land is sometimes considered as **fire climax**, i.e. it has a strong stability. Therefore, it is necessary to destroy this stability to provide opportunities to the introduced rubber stumps to grow and dominate the area. The use of chemical control using herbicides such as glyphosate (2.2 kg a.i./ha) or dalapon (8+7 kg a.i./ha) should be observed carefully since there is always regrowth from the remaining *I. cylindrica*

The typical results of spraying as compared with other methods can be observed in Table 1.

Table 1. *Imperata* population before and after treatment (plant/m²) and at harvest (% coverage) after some treatments and one season cropping

Treatments	Initial 3) population (plant/m²)	At 8 weeks 3) after spraying (plant/m²)	At planting 1) (plant/m²)	After maize and rice harvest 2) (% coverage)
1. Mechanical control	53.7	22.5 b	19.3 b	28.3 ab
2. Manual	44.2	27.3 b	18.9 b	35.0 b
3. Minimum tillage				
a. Dalapon (6.8 kg ai/ha) + 10 kg Urea + 1 l Teepol			5.8 a	22.5 a
b. Glyphosate (2.2 kg ae/ha)	68.7	3.5 a	3.9 a	17.5 a
4. Zero tillage, glyphosate (2.2 kg ae/ha)	58.8	3.5 a		
LSD	ns	8.3	3.1	5%
C.V.		(-)	20.0	23.9

1) adopted from Tjitrosemito *et al.*, 1985
2) adopted from Mangoensoekarjo *et al.*, 1987
3) adopted from Siswanto and Anwar, 1986

The spraying as soon in the Table 1 is very consistenly effective, but still leaves a considerable *Imperata* population, which still necessitate the application of spot spray and wiping. Wiping may be done using 1% glyphosate, or 2% dalapon, or diesel oil + kerosene at 60:40 mixture.

Recently imazapyr may also be applied, it normally requires 1 month after spraying before LCC can be planted.

However, when *Imperata* is killed, the growth of weed seed from unshaded soil will be very fast, it is very important therefore to control those emerging weeds in the growing Legume Cover Crop. It requires clean weeding at 2 weeks interval with 8-20 man working days/ha.

3. Old plantation (Replanting and Conversion Planting)

Weeds grow weaker under the shade of old plantation and are easier to control then they are under full sunlight, therefore, it is suggested to start controlling weeds one year before filling.

When the incidence of "White root disease" (*Rigidoporus lignosus*) is high, it is better to cultivate the soil and clean the area from any debris of plant roots and stumps; this condition is also an advantage for establishment of legume cover crops. However, the lower loss of trees and the saving in disease control measures after planting may not offset the high cost of stump and root removal compared with minimum tillage technique, in such situation soil cultivation with accompanying stump and root removal is not suggested.

The vegetation under old plantation may be classified into the following (Nasution, 1986; RRIM, 1972):

A. **Useful weeds or vegetations**, the growth and establishment of these vegetation should be encouraged.
B. **Harmless Annual Vegetation**, in a normal situation no special effort to control them is necessary.
C. **Perennial Vegetation**, usually tolerated as "soft grasses", but when excessive will require a particular control.
D. **Very Competitive Weeds**, should be controlled especially at the early of establishment of young rubber.
E. **Noxious weeds**, should be eradicated.

Table 2. List of common weeds in Rubber Plantation. (Modified from Sri S. Tjitrosoedirdjo, 1993).

Group/ Family	Species	Class
FERNS (Pteridophyte)		
1.	*Blechnum orientale*	B/C
2.	*Cyclosorus aridus*	B/C
3.	*Dicranopteris linearis*	D
4.	*Lygodium flexuosum*	B
5.	*Nephrolepis biserrata*	C
6.	*Selaginella willdenowii*	B/C
7.	*Stenochlaena palustris*	B/C
8.	*Taenitis blechnoides*	B/C
GRASSES (Poaceae)		
1.	*Axonopus compressus*	C
2.	*Brachiaria distachya*	D
3.	*Brachiaria reptans*	D
4.	*Centhotheca lappacea*	D
5.	*Coelorachis glandulosa*	D
6.	*Cynodon dactylon*	C
7.	*Cyrtococcum acrescens*	C/D
8.	*Cyrtococcum oxyphyllum*	C/D
9.	*Dactyloctenium aegyptium*	B/C
10.	*Digitaria ciliaris*	B/C
11.	*Echinochloa colona*	C
12.	*Eleusine indica*	B
13.	*Imperata cylindrica*	E
14.	*Ischaemum muticum*	B
15.	*Ischaemum timorense*	B
16.	*Ischaemum rugosum*	D
17.	*Oplismenus compositus*	D
18.	*Ottochloa nodosa*	C
19.	*Paspalum comersonii*	D
20.	*Paspalum conjugatum*	C

Group/ Family	Species	Class
	21. *Pennisetum polystachion*	D/E
	22. *Setaria barbata*	D/C
	23. *Setaria palmifolia*	D/E
	24. *Sporobolus diander*	D
	25. *Themeda arguens*	D/C
	26. *Themeda villosa*	D/E
SEDGES (Cyperaceae)		
	1. *Cyperus kyllingia*	C
	2. *Cyperus rotundus*	D
	3. *Scleria bancana*	D
	4. *Scleria ciliaris*	D
	5. *Scleria levis*	D
	6. *Scleria sumatrensis*	D
	7. *Scleria purpurascens*	D
CLIMBERS		
	1. *Abrus precatorius*	C
	2. *Calopogonium mucunoides*	A
	3. *Centrosema pubescens*	A
	4. *Cardiospermum halicacabum*	C
	5. *Desmodium triflorum*	A
	6. *Dioscorea nummularia*	C
	7. *Ipomoea cairica*	C
	8. *Lepistemon binectariferus*	B
	9. *Melothria affinis*	B
	10. *Merremia umbellata*	D
	11. *Mikania micrantha*	E
	12. *Passiflora foetida*	B
	13. *Pueraria javanica*	A
	14. *Tetracera indica*	D
	15. *Tetracera scandens*	D
	16. *Trichosanthes walliciana*	D
	17. *Vitis japonica*	D
SHRUBS		
	1. *Chromolaena odorata*	D
	2. *Clibadium surinamense*	D
	3. *Clidemia hirta*	D
	4. *Cordia curassavica*	D
	5. *Diodia sarmentosa*	D
	6. *Ficus hirta*	D
	7. *Grewia tomentosa*	D
	8. *Lantana camara*	D
	9. *Melastoma affine*	D
	10. *Sida rhomboidea*	D
	11. *Sida acuta*	D
	12. *Triumfeta rhomboidea*	D
	13. *Urena lobata*	D

Group/ Family	Species	Class
MIMOSACEAE		
1.	*Mimosa invisa*	E
2.	*Mimosa pigra*	E
3.	*Mimosa pudica*	D
HERBS		
1.	*Ageratum conyzoides*	B
2.	*Ageratum haustonianum*	B
3.	*Borreria laevis*	C
4.	*Borreria latifolia*	C
5.	*Cleome rutidosperma*	B
6.	*Commelina benghalensis*	C
7.	*Commelina diffusa*	C
8.	*Crassocephalum crepidioides*	B
9.	*Croton hirtus*	B
10.	*Curculigo villosa*	C
11.	*Desmodium triflorum*	A
12.	*Dianella nemerosa*	B
13.	*Emilia sonchifolia*	B
14.	*Euphorbia hirta*	B
15.	*Euphorbia heterophylla*	C
16.	*Hyptis capitata*	D
17.	*Hyptis brevipes*	D
18.	*Phylanthus amarus*	B
19.	*Phylanthus reticulatus*	B
20.	*Rostellularia obtusa*	B
21.	*Stachytarpheta indica*	D
22.	*Trimeza martinicensis*	B

The vegetation may be dominated by either of those groups, or most likely they grow together with group D and E dominating the vegetation when the plantation is kept with only minimum maintenance.

Initially weeds of group E and D are normally eradicated at year -1 followed by rubber tree felling. Weeds of D E groups consisting shrubs and woody weeds are normally eradicated first. When the density is infrequent it is enough to uproot manually; however, when they are very dense, Picloram (TORDON 101) at 4-6 lt/ha or trichlopyr at 1.2-2.4 kg a.i./ha are more practical; weeds of D E group consisting of grasses glyphosate at 1.2-1.5 kg a.e./ha are sufficient. The weed of ABC group, when the density is only infrequent up to frequent, paracol at 1.5 lt/ha will be sufficient to keep them from growing, until LCC planting is carried out; however when they are very dense, they will require glyphosate at 3 lt/ha to keep them in check. When soil is sloping necessary terracing, and other soil conservation measures should be observed (see under forest land) beside road network.

After eradication of D, E weeds and felling of rubber trees, it is immediately followed by lining and holing, i.e. preparation for planting. Legume cover crops are planted in between rows of holes.

A typical series of activities, when the area is less than 200 ha can be seen in Table 3.

Table 3. Integrated *Imperata* control into other activities before rubber planting in PTP XI West Java (Adopted from Tjitrosemito & Mawardi, 1993)

No.	Activities	J	F	M	A	M	J	J	A	S	O	N	D
1.	Delineating field	x	.	.	.	.	.	.	.	.	.	.	.
2.	Fell big trees	x	x	.	.	.	.	.	.	.	.	.	.
3.	Slashed shrubs	.	.	x	.	.	.	.	.	.	.	.	.
4.	Uproot shrubs	.	.	x	.	.	.	.	.	.	.	.	.
5.	Uproot big trees	.	.	.	x	.	.	.	.	.	.	.	.
6.	Windrowing-burning	.	.	.	x	.	.	.	.	.	.	.	.
7.	Spray *Imperata*[1]	.	.	.	.	.	x	.	.	.	.	.	.
8.	Correction spray[2]	.	.	.	.	.	.	x	.	.	.	.	.
9.	Spot-spray *Imperata*[3]	.	.	.	.	.	.	.	.	x	.	.	.
10.	*Imperata* hunting[4]	.	.	.	.	.	.	.	.	.	.	.	. x
11.	Road construction	.	.	.	.	x	.	.	.	.	.	.	.
12.	Drainage construction	.	.	.	.	x	.	.	.	.	.	.	.
13.	Lining	.	.	.	.	.	.	x	.	.	.	.	.
14.	Soil conservation/terracing	.	.	.	.	.	.	.	x	x	x	.	.
15.	Holing	.	.	.	.	.	.	.	x	x	x	.	.
16.	Weeding before planting LCC[5]	.	.	.	.	.	.	.	.	x	.	.	.
17.	Weeding after planting LCC	.	.	.	.	.	.	.	.	.	.	.	.
18.	Circle weeding	.	.	.	.	.	.	.	.	.	.	.	. x
19.	Pest/disease control	.	.	.	.	.	.	.	.	.	x	.	x
20.	Fertilization of LCC	.	.	.	.	.	.	.	.	.	.	.	x
21.	Planting LCC	.	.	.	.	.	.	.	.	.	.	x	x
22.	Planting rubber	.	.	.	.	.	.	.	.	.	.	x	x
23.	Fertilization of rubber	.	.	.	.	.	.	.	.	.	.	.	x

1 : using glyphosate at 1.44 kg ae./ha
2 : using glyphosate at 0.36 kg ae./ha
3 : using glyphosate at 1.1 kg ae./ha
4 : wiping glyphosate at 1 %
5 : using glyphosate at 1.1 kg ae./ha (against grasses other than Imperata)

B. Lining and Holing

When the area is cleared of trees, shrubs, and robust grasses, lining and holing can be carried out. When the area is flat line marking is easier. Usually a base line is fixed on the longest boundary of the area, running from north to south. The base line is made with the help of steel wire tagged according to interrow distance by extending it from a corner peg and placing a second corner peg at its end; other pegs are then put in on the base line at each planting point marked on the wire. In the east-west direction another guide perpendicular to the base line is fixed and tagged with at in row distance. Starting from the baseline, the wire of inter-row distance is held at its north and south ends by two men who advance east-west. They stop at each tag on the guide line, while other men place pegs at the planting point along the wire.

When the area is sloping, the planting rows are established on terraces to follow contour lines. The distance from centre to centre of adjacent terraces is equal to the normal inter-row in flat condition. A base line is marked out at right angle to the contour, down an average slope of the area. Pegs are put in at the interrow planting distance down the length of base line. The slope is usually not uniform, therefore when the distance between terraces is reduced by 2/3 of the normal distance the terrace is terminated; if the distance is more or equal to 1 1/3 normal, an additional terrace should be prepared; when the slope is more than 30%, the plant is planted in individual terraces.

Holes are made by cangkul measuring 60 x 60 cm at the surface, tapered down to 40 x 40 cm at 50 cm depth. Each hole is fertilized with 300 g of rock phosphate.

C. Establishment of LCC

When the availability of labour is low, LCC is planted one year ahead of its crops; however when the area is only small and the availability of labour is high, LCC and crops can be planted in the same year.

There are many species of legume cover crops such as *Pueraria javanica, P. pasheloides, Calopogonium mucunoides, C. caeruleum, Centrosema pubescens*, etc.; but in Lampung and West Java *P. javanica* (at 7.0 kg/ha) and *C. caeruleum* (1 plant/m) are very common. *P. javanica* is planted in 4 rows, i.e. 2 rows are at 1.5 m distance from the rubber rows the next row is 1.0 m apart with a central rows planted with *C. caeruleum. P. javanica* is planted at about 122.5 g/m row and mixed with an equal amount of rock phosphate. Cutting of *C. caeruleum* is fertilizer with 10 g rock phosphate/plants and planted at 1.0 m distance.

NURSERY

In nursery, the planters have the greatest opportunity to obtain the best planting materials through careful selection and appropriate agronomical practices. If farmers do not utilize this opportunity properly and plant a second grade budded stumps, the farmers will suffer a considerable loss in the entrepreneurship in the form high cost of maintenance with the accompanying low yields.

There are two nurseries, i.e. for root-stocks and bud-wood. The strict selection of plant materials from seeds, seedling, grafting, bud form, vigor and careful husbandries on the best environment, with adequate moisture and nutrients, **free of weeds**, pathogens, insect and vertebrate pests will ensure a healthy, vigorous and strong budded stumps. It is the first pre-requisite of a good rubber plantation.

1. Root-stock nursery

The process of establishing root-stock nursery involves a series of activities from constructing germination bed, germinating selected seeds, transferring seedlings to a nursery of selected site, maintenance of seedlings for 4-6 months (for green budding) or 8-12 months (from brown-budding) until grafted with the appropriate scion.

The site for rootstock nursery is carefully selected, cleared from other vegetation, thoroughly cultivated and must be kept weed free until seedlings are planted at 40 x 40 cm double rows; row distance is 60 cm. Seedlings are planted in holes of 5 cm deep.

Weed management is directed toward clean-weeding in every step of those series of activities. A greater attention should be observed when seedlings have been transferred to the nursery. Weed control rotation must be adhered closely. When carried out manually it requires once every 10 days in the first month, once every 15 days in the second and third month, and once at the monthly interval from the forth month onward until grafting. However, when labor is scarce, chemical control can also be applied i.e, mixture of alachlor + linuron at 0.5 kg a.i./ha each at 1-5 days after planting; it is good for about 3 month; after that paracol (paraquat + diuron 0.5 kg ae/ha at 2 monthly interval are good enough (Yeoh *et al*, 1980); Care should be taken to avoid herbicide contact with the stem and leaf of young rubber.

2. Budwood nursery

This nursery is directed toward producing sufficient scion to be grafted to young rubber from the rootstock nursery. The planting materials in the form of stump are planted at 100 x 80 cm. The size of the nursery has to be calculated carefully to ensure sufficient quantity of scions to be grafted. One year old bud wood will produce 20 scion/m; bud wood rubber of 1.5 year old having experienced twice cuttings will produce 6-8 new branch each having 3-4 good scion. As the planting distance is wide than that in root stock nursery, weed management requires a more effort here; basically it is similar to that of root stock nursery in that it requires also clean weeding.

3. Grafting

There are two types of grafting available, brown and green budding. The technique is similar, the later one is only recently carried, and is more difficult, but can be done on rootstock of only 4-6 month old. The success of grafting is highly affected by soil moisture condition, when evaporation is producing water deficit, grafting should be postponed until the soil moisture is more favorable.

The maintenance of grafted rootstock may be carried out "in situ" or planted in polybags before being transplanted to the field. Planting the budded stump in polybag is much favored, as more maintenance can be carried to ensure a good planting material in the field.

Weed management is directed toward clean weeding both for weeds in the polybags as well as the surrounding.

FIELD PLANTATION

When the intended field for establishing rubber plantation has been thoroughly prepared and the budded stump either direct from the root stock nursery after being grafted, or in polybags are available at sufficient quantity, then transplanting can be carried out.

Transplanting is carried out carefully by considering the topography, planting distance, as well as whether Legume Cover Crop are planted or not. Planting distances vary from 4 x 5 m to 7 x 3 m or 8 x 2.5 m with a population of around 500 budded stump/ha.

In any case weed management activities can be differentiated into those rubber plantation at :

a) 0 - 2 years old
b) 3 - 5 years old
c) 6 - 15 years old
d) 16 - 25 years old

1. Rubber plantation of 0 - 2 years old

The activities on weed management are extremely important here. The introduced budded rubber stump is only around 500 plants/ha, and yet the weed population is almost unlimited. It is compulsory, therefore, to control vegetation sufficiently to provide enough opportunity for rubber stump to grow, develop and dominate environment.

The area is usually differentiated between (1) the circle around the introduced rubber and (2) outside the circle. The circle of 1.0-1.5 m radius around the young rubber is demanded to be free of weed; and weeding is usually carried out manually through light soil cultivation 10-12 time per year requ-iring 3-4 MWD/ha. While it seems to require a tremendous labor input, the input will be much higher when at this stage weed management is neglected.

Outside the circle the vegetation should be managed seriously. When LCC is planted it is good to follow the following rotation, and done manually by pulling and uprooting the weed: 1st-6th month requires 8-15 MWD/ha, 6th-12th month requires 5-6 MWD/ha, 12th-24th month requires 4 MWD/ha.

When weeds of D and E types are present abundantly the plantation is in a very bad situation. It has been a mistake along the line some where during the pre-planting stages, either cultivation with nursery, or negligence in later plantation husbandry. In any case weeds of D and E types must be eradicated.

Imperata cylindrica and other unwanted grasses can be controlled using glyphosate at 2.0-4.0 kg ai/ha when exists in a dense up to very dense population with blanket spray (dense) or spot spray (frequent); when the population is only infrequent, wiping using glyphosate 1%, dalapon 2%, or diesel oil + kerosene mixture at 60+40 is better, while shrubs may uprooted or sprayed with picloram or triclopyr at 1.2-2.4 kg ai/ha.

2. Rubber plantation of 3 - 5 years old

At this stage the growth of rubber plantation when kept normally at least will have girth measurement of 8.0 - 10.0 cm. The circles of each trees are joint to form a strip along the row of rubber trees.

Weed control in strip, or rows, will be much more intensive before manuring. As at this stage the population of weeds in strips has gone up also, chemical control is usually more frequently applied. Weed management in between rows is directed eradication of D and E types of weeds.

3. Rubber plantation of 6 - 15 years old

When the standard practice of plantation husbandry is carried out normally, at this stage the plantation should have been capable. The canopy is closing reducing the light penetration. The population of LCC is reduced so is the population of weeds. As rubber also experience leaf falling during the dry season, the population of D and E types should always be observed.

4. Rubber plantation of 16-25 years old

The strip weed population still require contro, weeds of D and E types are not allowed to grow but toward the year of 20th the vegetation is allowed to grow in between rows as at this stage the rubber is close to replanting again.

ACKNOWLEDGEMENT

The author gratefully acknowledge Prof.Dr. Kozo Ishizuka, President of APWSS, chairperson the Organizing Commitee of the 15^{th} APWSS Conference for providing travel and accomodation funds to participate in the 15^{th} APWSS Conference.

LITERATURE

Eussen, J.H.H. 1981. Studies on the Growth Characteristics of Alang- alang (*Imperata cylindrica* (L.) Beauv.) *BIOTROP Bulletin* 18: 32p. Jacobs, M. 1988. The Tropical Rain Forest: A First Encounter. New York. Springer - Verlog.

Mangoensoekarjo, S., S. Tjitrosemito, Nurdin and Siswanto. 1987. Reclamation of *Imperata* Field into a Plantation Based Agroproduction System. *Proc. 11^{th} Asian Pacific Weed Sci. Soc. Conf.* (II): 485-496.

Miles, J. 1979. Vegetation dynamics. London. Chapman and Hall. 80pp.

Nasution, U. 1986. Gulma dan pengendaliannya di perkebunan karet Sumatra Utara dan Aceh. Pusat Penelitian Tanjung Morawa (P4TM) (in Indonesian). 269 pp.

Nearing, W.A. and R.H. Goodwin. 1976. Creation of relatively stable shrublands with herbicide; arresting "succession" on rights of way and pasture lands. *Industrial Vegetation Management 8* (1): 14-20.

Newton, M. 1981. Ecological principles of weed control in forestry *in* Weed control in forest management. *Proceeding of the 198l J.S. Wright For. Conf.* (Hold & Fisher : eds.). Purdue research Foundation. West Lafayette, Indiana.

Odum, E.P. 1969. The strategy of ecosystem development. *Science* 164: 262-270.

RRIM. 1972. Cover Management in Rubber. *Planters Bull.* Rubber Res. Inst. Malaysia. 122: 170-180.

Siswanto and C. Anwar. 1986. Pembukaan Padang Alang-alang pada Tanah Podsolik Merah-kuning untuk Mengembangkan Pola Usaha Tani Karet. Rakyat. *Laporan Penelitian.* Puslitbun Sembawa, Palembang. Indonesia. 1-5.

Tjitrosoedirdjo, Sri S. 1993. Identification of Weeds in Rubber Plantation; Decision Tree for an Expert Systems. Paper presented to the *Regional Workshop on Expert Systems in Weed Identification and Management in Rubber Plantation,* 31 January - 3 February 1994, BIOTROP, Bogor. 6p.

Tjitrosemito, S. and I. Mawardi. 1994. Weed Management in Rubber Plantation, A Prototype of an Expert System. *Proc. 2^{nd}. SEAWIC Advisory Board and Evaluation Meeting*, 7-9 February 1994. Bogor. Indonesia. 26-31.

Tjitrosemito, S., J. Wiroatmodjo and S. Effendi. 1985. The conversion of *Imperata* dominated area into rubber plantation. *Proc. 10^{th} Asian Pacific Weed Science Society Conf.* (II): 689- 699.

Tjitrosemito, S., S.S. Sastroutomo & I. H. Utomo. 1989. The Management of weeds in young rubber plantation. *Weed Leaflet* No. 1. SEAWIC BIOTROP. 2p.

Tjitrosoemito, S. 1991. The use of herbicides to establish an agricultural production system in *Imperata* dominated land. *Thesis*. Kobe University, Japan.

Current Status of Rice Herbicide Use in the Tropics

Nai-Kin Ho

Muda Agricultural Development Authority (MADA) ALOR SETAR 05050 MALAYSIA

Abstract. Chemical weed control for rice in the tropics began with the use of the chloroplenoxy herbicides in the 50s. MCPA and 2,4-D were used routinely in transplanted wetland rice for controlling broadleaved weeds and sedges. Propanil was introduced subsequently in the mid 60s as post-emergence control of annual grasses such as Echinochloa crus-galli and Leptochloa chinensis. Over the past decades, intensive research has led to the discovery, development and marketing of the wide spectrum of rice herbicides in the tropics. Those used include bensulfuron methyl, pyrazosulfuron-ethyl, cinosulfuron, bentazon, butachlor, piperophos thiobencarb, quinclorac, fenoxaprop-ethyl, molinate, pretilachlor oxadiazon, piperophos, dimethametryn, bifenox, pendimethalin and oxyfluorfen. The switch from transplanted to direct-seeded rice in recent years has triggered more weed infestation in tropical rice. Herbicides are the only logical alternative for weed control in direct-seeding culture; however, continuous herbicide application causes a distinct shift in the weed flora from annuals to perennials. Repeated use of the same herbicide also results in the development of herbicide tolerant strains or resistant biotypes. Increasing herbicide usage has created concern regarding hazards to rice farmers' health. In the next decade, rice herbicide use in the tropics is expected to expand further because of increasing popularity of direct-seeded rice in the irrigated areas. It is therefore imperative to evaluate the impact of herbicides from the perspective of social implication such as potential environmental and health costs. Experiences of integrated weed management in malaysia reveal that it is possible to reduce herbicide application through farmers' education with emphasis on proper cultural practices and good water management.

Keywords: Herbicides, Weed Shift, Direct seeding.

Introduction

The successful synthesis of phenoxy derivatives in the 1940s triggered a significant change in rice weed management in the tropics. The herbicide 2, 4-D (2, 4-dichlorophenoxy acetic acid) was initially tested in the Philippines in 1948 to eradicate weeds in lawns and pastures, and subsequently tested for weed control in rice. Other herbicides and growth inhibitors were subsequently studied in 1955 (Mercado, 1979). In Thailand, 2, 4-D was considered as the only promising herbicide for the rice crop when it was introduced in the late 50s (Teerawatsakul, 1981). In Malaysia, chemical control for rice began with the use of 2, 4-D amine in the early 60s in the Muda Irrigation Scheme. However, herbicide usage was limited. The introduction of the wettable powder formulation of 2, 4-D butyl ester in the early 70s gave the impetus needed to boost the use of herbicides. This product was commonly hand broadcast in the rice fields together with urea and other granulated insecticides at 15 - 25 days after transplanting (DAT), thus saving time and labour for separate pesticide application (Ho, 1983). In Indonesia, progressive rice farmers in North Sumatra started using MCPA (2-methyl 4-chlorophenoxy acetic acid) to control broadleaved weeds and sedges in

1972. Farmers subsequently switched to 2, 4-D in 1978 due to shortage of MCPA. Indonesian farmers preferred the use of 2, 4-D because the price was lower and it did not require sprayers for application (Sundaru, 1981).

Since the introduction of phenoxy compounds four decades ago, intensive herbicide research has led to the discovery, development and marketing of a wide spectrum of herbicides. This has paved the way for wider herbicide use for rice-cultivation in the tropics (Table 1). This paper deals with some aspects of the current status of herbicide use in transplanted and direct seeded rice. Future challenges in chemical weed management in the tropics are also discussed.

Status of Herbicide Use in Transplanted Rice

Manual weeding is still commonly practised in transplanted rice. However, manual weeding is laborious and expensive. Moody (1994a) reported that weeding transplanted rice once at the appropriate time required approximately 25 labour days/ha. Therefore, the use of herbicides is more practical, effective and economical than manual weeding in achieving weed control and reducing crop losses.

In the tropics, the chlorophenoxy herbicides 2, 4-D and MCPA are used as routine weed control measures for sedges and broadleaved weeds in transplanted wetland rice. The most common formulations are the sodium and potassium salts available as water soluble powder or water-soluble liquid. Propanil was introdused in the mid 60s as a post emergence contact herbicide for grassy weed control (De Datta and Herdt, 1983). Extensive studies conducted subsequently over the past three decades revealed that herbicides suitable for use in transplanted rice include *bensulfuron-methyl, pyrazosulfuron-ethyl, bentazon, butachlor, 2, 4-D, MCPA, piperophos + 2, 4-D, propanil, thiobencarb, quinclorac* and *fenoxaprop-ethyl* (Moody, 1994b).

In Malaysia, 2, 4-D isobutyl ester and 2, 4-D amine are more popular than the other phenoxy derivatives. Approximately 95% of rice farmers who practised chemical weed control in the Muda Irrigation Scheme use these two herbicides for post emergence weed control in transplanted fields against sedges such as *Fimbristylis miliacea (L.) Vahl, Cyperus difformis Linn, Scirpus grossus Linn.f.* and annual broadleaved weeds such as *Monochoria vaginalis (Burm.f) Presl, Sagittaria guyanensis Humb and Limnocharis flava (L.) Buch* (Ho and Md. Zuki, 1989). The extensive use of 2, 4-D compounds for post-emergence application has enabled the Muda farmers in Malaysia to keep the annual sedges and broadleaved weeds under control. However, aquatic ferns, such as *Marsilea minuta* and *Salvinia molesta* D.S. Mitchell, which are tolerant to 2, 4-D, remain problematic in the transplanted fields (Ho, 1991). In the late 80s and early 90s, sulfonylurea herbicides became popular because of their excellent control over *M. minuta, S. molesta* and *Sphenoclea zeylanica Gaertn* (Ho, 1994).

In the Philippines, selective herbicide such as *butachlor* and *thiobencarb* are popular as pre-emergence and post-emergence herbicides for annual grassy-weed control. Remarkable selectivity against *Echinochloa* and other weeds species make thiobencarb an excellent herbicide for transplanted rice (De Datta and Herdt, 1983).

In Thailand, 2, 4-D and butachlor are the most popular herbicides based on the total quantity imported. The most common herbicides used for transplanted rice are *thiobencarb, bifenox, butachlor, CNP, oxadiazon, piperophos, dimethametryn* and *bensulfuron methyl*. These herbicides are generally applied 5 - 8 days after transplanting. The effectiveness of these herbicides are very much dependent on the maintenance of suitable water level in transplanted rice (Vongsaroj, 1993).

In Indonesia, the application of slow-release formulations of thiobencarb and butachlor is currently being studied. Preliminary investigations indicate that although these chemicals do not give better weed control than the existing commercial formulations, they are more compatible with integrated fish-rice culture (Suyud, 1992).

Status of Herbicide Use in Direct Seeded Rice

In recent years, the increase in irrigated areas, inexpensive herbicides, development of early-maturing modern varieties, knowledge on efficient fertiliser management, and socio-economic constraints encouraged many farmers in the Philippines, Thailand and Malaysia to switch from the traditional transplanted to direct-seeded rice culture; (De Datta, 1986). Escalation of transplanting cost and shortage of farm labour provided further impetus to widespread adoption of the labour-saving direct seeding technique in South East Asia.

Weed control is more critical and difficult in direct-seeded rice than in transplanted rice. This is because of the similarity in size and morphology of rice seedlings and grass weeds of the same age (De Datta and Bernasor, 1973). Yield losses due to uncontrolled weed growth at IRRI, Philippines were on an average 9% higher in wet-seeded rice than in transplanted rice (Moody, 1983). In dry-seeded rice, weed problems are more acute than in other rice cultures because a lack of water at early crop establishment stage triggers more weed infestations. Moody and Cordova (1985) reported that herbicides are the only logical alternative for weed control in wet-seeded rice.

In Malaysia, virtually all the rice farmers who practised direct seeding in the Muda area adopted chemical weed control (Table 2). Herbicides commonly used for grassy weed control in the direct seeded fields are *propanil, propanil + thiobencarb, pretilachlor + safener, quinclorac, molinate, molinate + propanil* and *fenoxaprop-p-ethyl* (Ho, 1994). Baki and Azmi (1992) reported that *pretilachlor* at 0.5 kg ai/ha applied 3 - 5 DAS, or a *mixture of molinate + 2, 4-D IBE* (2.5 + 0.5 kg ai/ha); *molinate + bensulfuron* (2.5 + 0.03 kg ai/ha); *thiobencarb + 2, 4-D IBE* (2.5 + 0.5 kg ai/ha); *oxadiazon + 2, 4-D IBE* (0.5 + 0.5 kg ai/ha); *propanil + molinate* (2.5 + 0.5 kg ai/ha) and *cinosulfuron* (0.04 kg ai/ha) applied at 8 - 10 DAS on moist or moderately inundated field conditions (5 - 10 cm depth), can control a broad spectrum of sedges, grasses and broadleaved weeds.

In the Philippines, the shift to wet-seeding resulted in a shift to herbicide use (Casimero et al, 1994). Studies conducted in Nueva Ecija revealed that 71% rice farmers who practised wet-seeding used only chemical control, whereas 52% of farmers who transplanted their crops used only herbicides for weed control (Table 3) (Erguiza et al, 1990). The herbicides most widely used in the Philippines are *butachlor* and *thiobencarb* (De Datta and Flinn, 1986).

In Thailand, some commonly used herbicides are *butachlor, thiobencarb, oxadiazon, piperophos* and *dimethametryn* (Vongsaroj, 1987). *Bifenox* and *oxadiazon* are often used after the rice seeds have been broadcast in dry-seeded, wet-seeded and deep water rice. Herbicide combinations such as *2, 4-D + propanil, propanil + molinate* and *propanil + thiobencarb* are applied when weeds reach the 2 - 3 leaf stage. For upland rice, *bifenox, pendimethalin, oxadiazon* and *oxyfluorfen* are used after seeding (Vongsaroj, 1987).

Issues Related to Herbicide Use

a) Weed Shift

Reliance on a single herbicide could result in quantitative changes in the structure of the weed population in as few as 5 years (Mahn and Helmecke. 1979). In the tropics, a distinct shift in the weed flora from annuals to perennials occur after continuous herbicide application. Repeated applications of herbicides in the Philippines have resulted in *Echinochloa crus-galli* and perennial sedge became increasingly dominant (Vega et al, 1971; De Datta, 1977). Annual weeds in the early croppings were replaced by the perennial grass *Paspalum distichum L.* after continuous treatment with *piperophos + 2, 4-D, pendimethalin* and *butachlor* (Janiya and Moody, 1987).

In Indonesia, the population of *Echinochloa crus-galli* (L.) Beauv is increasing in transplanted rice with the continuous use of 2, 4-D and metsulfuron methyl for broadleaved weed control (Moody, 1991).

In the Muda area of Malaysia, continuous use of 2, 4-D applied as post-emergence control has caused the suppression of the easy-to-control weeds such as *Monochoria vaginalis* and *Fimbristylis miliacea*, resulting in a distinct dominance of *Echinochloa crus-galli, Sphenoclea zeylanica, Marsilea minuta, Cyprus iria* and *C. babakan*. The application of pretilachlor with fenclorim as safener has shown remarkable crop selectivity and bio-efficacy in grassy weed suppression, but provided a conducive environment for *Sagittaria guyanensis* and *M.minuta* to prevail (Figure 1). Molinate suppresses *E. crus-galli*, but results in escalated infestation of *Leptochloa chinensis* (L.) Nees and *Ischaemum rugosum Salisb* (Ho, 1991).

b) Herbicide Resistance

Herbicide tolerant strains or resistant biotypes could evolve through repeated use of the same herbicide over a long period. Le Baron and Mc Farland (1990) revealed that there are 113 weed biotypes which are resistant to the 15 classes of herbicides in the world. A few of these are claimed to have evolved resistance to some herbicide classes by cross resistance.

In South-east Asian rice fields, the 2, 4-D tolerant biotype of *Sphenoclea zeylanica* was first reported in the Philippines (Migo et al, 1986). Subsequent studies by Mercado et al (1987) reported that this tolerance is attributed to the thicker cuticle observed in the third and fifth leaf position which possibly resulted from continuous use of 2, 4-D.

In the Muda area of Malaysia, a 2, 4-D resistant biotype of *Fimbristylis miliacea* was first detected in 1989 in a farmer's field where 2, 4-D has been seasonally applied since 1975 (Ho, 1992). Subsequent studies conducted by Watanabe et al (1994) indicated that the resistant biotype recovered after the application of 2, 4-D amine at 16 times strength over the recommended dosage. This resistant biotype showed cross resistance to other phenoxy compounds such as 2, 4-D isobutyl ester, 2, 4-D sodium salt and MCPA.

c) Herbicide Poisoning

In recent years, increasing use of herbicides in rice cultivation has created concern regarding the hazards to the health of rice farmers. In Malaysia, a recent survey on pesticide usage and associated incidence of poisoning in the Muda area indicated that herbicides were most commonly used when compared with insecticides, fungicides and rodenticides. Approximately 51.3% of the responding farmers reported that they had experienced symptoms associated with pesticide poisoning. The highest incidence was due to herbicide application alone (24.8%), followed by insecticides (14.7%). Farmers rarely experienced poisoning symptoms due to rodenticides or fungicide. Headache and dizzeness (71.6%) were most commonly experienced by the respondents. The types of herbicide identified by farmers and spray operators were *2, 4-D, paraquat, molinate* and *metsulfuron methyl* (Ho et al, 1990).

In the Philippines, studies conducted by Rola and Pingali (1992) found that the use of phenoxy derivatives was linked to the incidence of pterygium (eye irritation), bronchial asthma, pulmonary disorders, low haemoglobin and polyneuropathy. The reported incidence of pterygium in the surveyed villages was five to seven times greater than that in the control villages that did not use herbicides in rice production.

Outlook of Herbicide Use in the Tropics

In the next decade, it is envisaged that rice weed management will not differ drastically from current practices. However, the area treated with herbicide is expected to expand because of the increasing popularity of direct seeding in the irrigated rice areas (Moody, 1994b). In the tropics, the rice herbicide market is expanding. Woodburn (1993) reported that herbicide use in Thailand has increassed dramatically in the late 80s and early 90s. Products such as *bensulfuron methyl, pretilachlor* and *fenoxaprop ethyl* have benefitted although the old herbicides 2, 4-D and butachlor remained important. A similar trend is being observed in Malaysia (Ho, 1994).

The adoption of herbicides is very much dependent on the return of input investment relative to other weed control measures. Ampong Nyarko and De Datta (1991) showed that the marginal benefit - cost ratio of chemical weed control in transplanted rice was 16 : 1 whilst that for manual weeding was only 3.3 : 1. The relative cheapness and efficacy of herbicides and their contribution towards reducing drudgery in manual weeding is indeed a remarkable achievement in modern rice cultivation. However, it is imperative to evaluate the impact of chemical weed management technologies from the perspective of social implications of herbicide use. Some of the potential environmental and health costs listed by Naylor (1994) are as follows:-

. Chronic health and environmental damage associated with the contamination of ground and surface waters

. Herbicide residues in food chains

. Increased mortality and alteration of population among the flora and fauna in the rice agro-ecosystem

. Occurrence of weed shifts and herbicide-resistant weed

. Elimination of beneficial plants as refuge for biological agents.

Over-reliance on herbicides discourages the development of other weed management alternatives. This will seriously hinder any reduction of dependence on herbicides (Moody, 1994). Integrated weed management (IWM) which emphasises the integration of several weed control measures applied simultaneously (Moody and De Datta, 1982) is the best approach from the agronomic, economic, social and ecological standpoints. In the Muda area of Malaysia, the successful launching of a large-scale campaign during 1989 based on the IWM concept reduced *Echinochloa* infestation by 66% and increased rice yields by 27% (Ho et al, 1990).

Lessons learnt from continuous monitoring of weed-rice interaction in the Muda area of Malaysia indicated that the total eradication of weeds is not practical in the rice agro-ecosystem. The removal of the last 5% of weeds remaining in the rice fields is usualy not cost effective. Besides, additional herbicide usage for total weed control creates concern about environmental side effects.

Although the use of herbicides is more widespread and expenditure in chemical control per hectare has increased (Table 2), the total quantity of herbicides used in the Muda area, Malaysia has declined in recent years (Figure 2). This is because improvement in cultural practices has reduced the frequency of herbicide application. Studies in the Muda area showed that farmers practising proper land preparation and good water management could manage their weed problems with only one round of herbicide application, whereas farmers adopting poor cultural practices usually apply herbicides 3 to 4 times per season to control weeds (Ho, 1994). Besides, the widespread adoption of pretilachlor (0.5 kg ai/ha), fenoxaprop-p-ethyl (0.06 kg ai/ha) to replace molinate (3.0 kg ai/ha), and the use of sulfonyl urea compounds (0.004 to 0.05 kg ai/ha) to replace 2, 4-D (0.8 to 1.0 kg ai/ha.) also helps to reduce herbicide usage and fish toxicity problems in the rice agro-ecosystem.

References

1. Ampong-Nyarko, K.; De Datta, S.K. (1991) A handbook for weed control in rice. International Rice Research Institute, Los Banos, Philippines. 113p.

2. Baki, B.; Azmi, M. (1992) The protocol of herbicide application in direct-seeded rice in Malaysia. Paper presented at International Weed Control Congress, Melbourne, Australia.

3. Casimero, M.C.; Cruz, R.T.; Obien, S.R. (1994) Weed management in wet-seeded rice in the Philippines. Paper presented at the International Workshop on Wet-Seeded Rice, 31 May - 3 June, 1994, Bangkok, Thailand. 20p.

4. De Datta, S.K. (1977) Approaches in the control and management of perennial weeds in rice. Pages 205 - 266 in Proceedings of the 6th. Asian-Pacific Weed Science Society Conference, Jakarta, Indonesia.

5. De Datta, S.K. (1986) Technology development and the spread of direct-seeded flooded rice in Southeast Asia. Exp. Agric. 22:417 - 426.

6. De Datta, S.K.; Bernasor, P.C. (1973) Chemical weed control in broadcast-seeded flooded tropical rice. Weed Research 13:351 - 354.

7. De Datta, S.K.; Herdt, R.W. (1983) Weed control technology in irrigated rice. Pages 89 - 108 in Proceedings of the Conference on weed control in rice, 31 August - 4 September, 1981. International Rice Research Institute, Los Banos, Philippines.

8. De Datta, S.K.; Flinn, J.C. (1986) Technology and economics of weed control in broadcast-seeded flooded tropical rice. Pages 51 - 77 in Weeds and the Environment in the Tropics. K. Noda and B.L. Mercado, eds. Asian-Pacific Weed Science Society, Chiangmai, Thailand.

9. Erguiza, A.; Duff, B.; Khan, C. (1990) Choice of rice crop establishment technique: transplanting vs wet seeding . IRRI Res. Pap. Ser 139. Los Banos, Philippines. 10p.

10. Ho, N.K. (1983) Status of pesticide application technology on small farmers in the Muda area. Paper presented at the second UPM - MAPPS course on pesticide application technology, Universiti Pertanian Malaysia, Serdang, 18 - 22 October 1983. 21p.

11. Ho, N.K. (1991) Corparative ecological studies of weed flora in irrigated rice fields in the Muda area. MADA monograph No. 44. Muda Agricultural Development Authority, Alor Setar, 05050 Malaysia. 97p.

12. Ho, N.K. (1994) Integrated weed management of rice in Malaysia: Some aspects of the Muda Irrigation Scheme's approach and experience. Pages 83 - 97 in Proceedings of FAO - CAB International Workshop on Appropriate Weed Control in Southeast Asia, 17 - 18 May, 1994, Kuala Lumpur, Malaysia.

13. Ho, N.K.; Md. Zuki, I. (1989) Status of weed control under direct seeded condition in the Muda area. Paper presented at the MADA/MARDI quarterly meeting 1/89 on 22 May, 1989. MADA, Alor Setar 05050, Malaysia. 31p.

14. Ho, N.K.; Md. Zuki, I.; Asna, B.O. (1990) The implementation of strategic extension campaign on integrated weed management in the Muda area. Paper presented at the Third International Conference on Crop Protection in the Tropics 20 - 23 March 1990, Genting Highland, Malaysia. 27p.

15. Ho, N.K.; Asna, B.O.; Aznan, A.; Rabirah, A. (1990) Herbicide Usage and associated incidences of poisoning in the Muda area, Malaysia - A case study. Pages 321 - 333 in Proceedings of the 3rd. Tropical Weed Science Conference, Kuala Lumpur, Malaysia.

16. Janiya, J.D.; Moody, K. (1987) Effect of continuous herbicide application on weed growth and yield of transplanted rice. Philippine Journal of Weed Science. 14:62 - 69.

17. Le Baron, H.M.; Mc Farland, J. (1990) Overview and prognosis of herbicide resistance in weeds and crops. pages 336 - 352 in Managing resistance to agro chemicals: From Fundamental research to practical strategics. ACS Symposium Series 421, Washington, D.C. USA.

18. Mahn, E.G.; Helmecke, K. (1979) Effect of herbicide treatment on the structure and functioning of agro-ecosystems: Structural changes in the plant community after the application of herbicides over several years. Pages 159 - 179 in Agro ecosystems Vol. 5.

19. Mercado, B.Z. (1979) Introduction to weed science. Southeast Asia Regional Center for Graduate Study and Research in Agriculture College, Laguna, Philippines. 292p.

20. Mercado, B.L.; De Datta, S.K.; T.R. Migo (1987) Growth behavior and leaf morphology of Philippine strains of Sphenoclea zeylanica showing differential response to 2, 4-D. Paper presented at the Asian-Pacific Weed Science Society Conference, 29 November - 5 December 1987, Taipei, Taiwan.

21. Moody, K. (1983) The status of weed control in rice in Asia. FAO Plant Protection Bulletin 30(3/4) : 119 - 123. Rome, Italy.

22. Moody, K. (1991) Crop weed complexity in low land rice. Pages 15 - 26 in Proceedings of the 13th Asian-Pacific Weed Science Society Conference - Jakarta, Indonesia.

23. Moody, K. (1994a) Economic and technical forces leading to increased herbicide use and some consequences. Paper presented at the conference on herbicide use in Asian rice production, 28 - 30 March 1994 Stanford University, California, USA.

24. Moody, K. (1994b) Weed management in rice. Pages 249 - 256 in Weed management for developing countries. FAO Plant Production and Protection Paper 120. Food and Agriculture Organization, Rome, Italy.

25. Moody, K; De Datta, S.K. (1982) Integration of weed control practices of rice in tropical Asia. Pages 34 - 37 in Weed Control in Small Farms. M. Soerjani, D.E. Barnes and J.O. Robson, eds Asian-Pacific Weed Sci. Soc. Biotrop Spec. Publ. No. 15. Bogor, Indonesia.

26. Moody, K.; Cordova, V.G. (1985) Wet-seeded rice. Pages 467 - 480 in Women in rice farming system, International Rice Research Institute, P.O. Box 933, Manila, Philippines.

27. Migo, T.R.; Mercado, B.L.; De Datta, S.K. (1986) Response of Sphenoclea zeylanica to 2, 4-D and other recommended herbicides for weed control in low land rice. Philipp. J. Weed Sci. 13: 28 - 38, Philippines.

28. Naylor, R. (1994) Herbicide use in Asian rice production. Paper presented at the conference in herbicide use in Asian rice production, 28 - 30 March, 1994, Stanford University, California, USA. 47p.

29. Rola, A; Pingali, R. (1992) Pesticides and rice productivity: an economic assessment for the Philippines International Rice Research Institute, Los Banos, Philippines.

30. Sundaru, M. (1981) Weeds in paddy field and their control in Indonesia. Pages 57 - 61 in FFTC book series No. 22. Food and Fertilizer Technology Center, ASPAC, Taipei, Taiwan.

31. Suyud (1992) Study of slow release formulation of thiobencarb and butachlor in fish-rice culture. Center Studies on Natural Resources, University of Indonesia, Jakarta.

32. Teerawatsakul, M. (1981) Weeds in paddy field and their control in Thailand, Pages 51 - 56 in FFTC book series No. 20, Food and Fertilizer Technology Center, ASPAC, Taipei, Taiwan.

33. Vega, M.R.; Paller Jr., E.C.; Lubigan, R.T. (1971) The effect of continuous herbicide application on weed population and on the yield of low land rice. The Phil. Agric 55: 204 - 209, Philippines.

34. Vongsaroj, P. (1987) Weeds in paddy field and their control. Paper presented at the workshop at Cholburi Province Dept. of Agric. Extension and Dept. of Technology and Economic Coorperation and Dept. of Agriculture, Bangkok, Thailand.

35. Vongsaroj, P. (1993) Integrated management of paddy weeds in Thailand in FFTC EB 367, Food and Fertilizer Technology Center, Taipei, Taiwan.

36. Watanabe, H.; Md. Zuki, I.; Ho, N.K. (1994) 2, 4-D resistance of Fimbristylis miliacea in direct-seeded rice fields in the Muda area. Pages 350 - 353 in Proceedings of 4th International Conference in Plant Protection in the tropics, 31 March 1994, Kuala Lumpur, Malaysia.

37. Woodburn, A. (1993) Rice - the crop and its agro chemicals market. Allan Woodburn Associates Ltd. Midlothian, U.K./Managing Resources Ltd., Cambridge, U.K.

Table 1 : Herbicides Used in Tropical Rice Fields

Herbicides	Rate (kg ai/ha)	Time of Application
Bensulfuron	0.05-0.07	6 - 8 DAT or DAS
Bensulfuron + metsulfuron (P)	0.0165 + 0.0035	5 - 18 DAT, 10 - 18 DAS
Bentazon	0.75-2.0	10-15 DAT or DAS
Bentazon + MCPA(P)	0.8 + 0.12	15-20 DAT or DAS
Bentazon + Propanil (P)	1-1.3+2-2.7	15-20 DAT or DAS
Bifenox	2.0	6 DAS
Bifenox + 2.4-D	2.0 + 0.66	6 DAS
Butachlor	1.5 - 2.0	3 - 7 DAT, 6 - 8 DAS
Butachlor + safener (P)	0.75	3 DAS
Butachlor + 2,4-D	0.75 + 0.6	6 - 8 DAS
Butralin	2.0	4 - 6 DAS
2, 4-D	0.5 - 0.8	15-25 DAT, 20 DAS
Cinosulfuron	0.04	8 - 10 DAS
Chlorimuron ethyl	0.008	20 DAT or DAS
Chlorimuron ethyl + metsulfuron	0.004+0.004	21 DAT or DAS
CNP	2.0	3 DAT or 5 DAS
EPTC + 2,4-D	1.2 + 0.6	7 - 10 DAT or 10 - 15 DAS
Fenoxaprop - ethyl	0.04 - 0.18	26 - 30 DAS
MCPA	0.5 - 0.8	20 DAT or DAS
Molinate	2.5 - 4.3	3-6 DAT, 8-10 DAS
Molinate + Propanil(P)	2-2.3+2-2.3	10 - 14 DAS

Herbicides	Rate (kg ai/ha)	Time of Application
Oxadiazon	0.75 - 1.5	10 - 14 DAS
Oxadiazon + propanil(P)	0.5 + 1.5	10 - 14 DAS
Oxyfluorfen	0.24	3 - 6 DAS
Pendimethalin	0.75 - 2.0	6 DAS
Pendimethalin + propanil (P)	2.6 + 1.07	8 - 10 DAS
Piperophos + dimethametryn	0.4 + 0.1	4 - 6 DAS
Piperophos + 2,4-D(P)	0.3 + 0.2	6 - 8 DAS
Pretilachlor + safener (P)	0.3 - 0.45	0 - 4 DAS
Propanil	3 - 4	10 - 14 DAS
Pyrazosulfuron	0.015-0.030	3-14 DAT,7-14 DAS
Quinclorac	0.25 - 0.50	0-5 DAT, 7-14 DAS
Sethoxydim	0.2	25 - 30 DAS
Thiobencarb	2 - 3	10 DAS
Thiobencarb + 2,4-D(P)	1.2 + 0.6	7 - 14 DAT, 10 - 14 DAS
Thiobencarb + propanil (P)	0.5 - 1.0 + 1.4 - 2.8	10 DAS
Trifluralin + 2,4-D(P)	0.6 + 1.0	10 - 15 DAS

DAT - days after transplanting

DAS - days after seeding

(P) - Proprietory product

Table 2 : Comparison of Herbicides Usage under different crop Establishment Methods (first season) in the Muda area, Malaysia.

Source : MADA (1994)

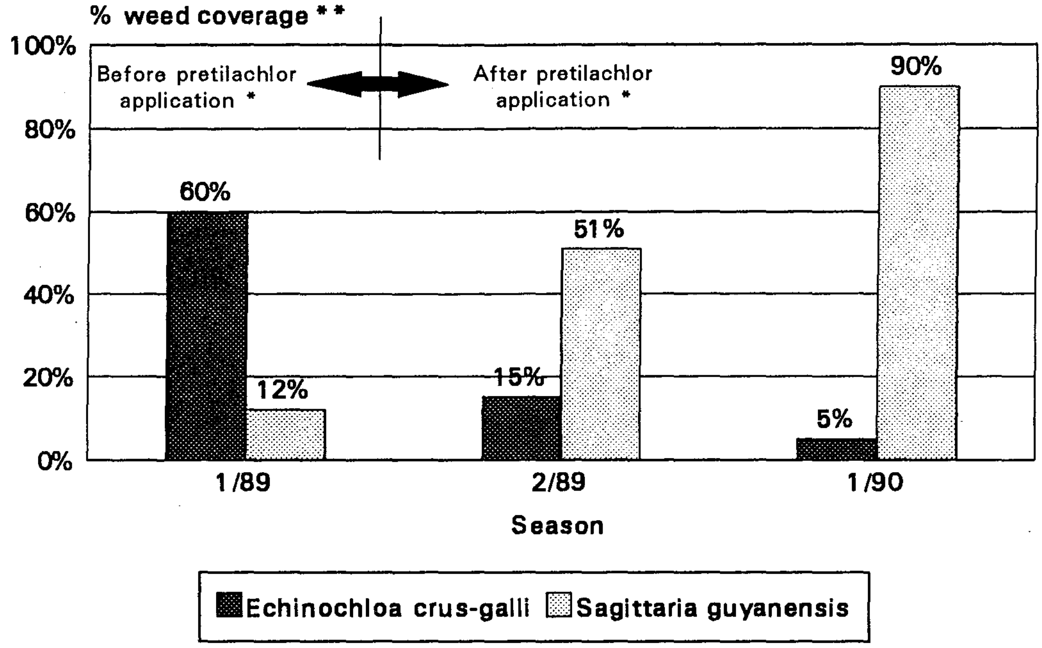
Farmers' Weed Control	1988		1994	
	Trans-planting	Direct Seeding	Trans-planting	Direct Seeding
Average Herbicide cost (US$/ha)	4.8	24.8	6.0	48.0
Farmers using herbicide (%)	82	98	86	100
Frequency of herbicide application (rounds/season)	1.2 (1 - 2)	2.9 (2 - 4)	1.0 (1)	2 (1 - 3)

* Figures in parentheses denote the range of herbicide application frequency

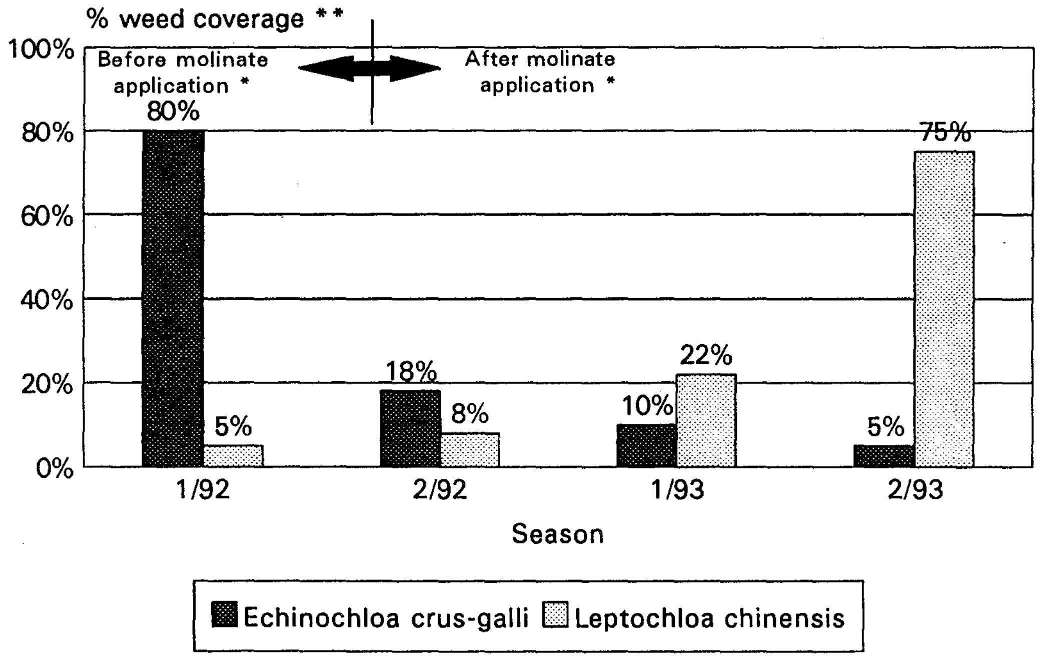
Table 3 : Weed Control practices by crop establishment method Nueva Ecija, Philippines, 1986 Dry Season (Adapted from Erguiza et al 1990)

Weed Control Method	Transplanted		Broadcast-seeded flooded	
	Farms (no)	%	Farms (no)	%
Manual only	9	8	0	0
Chemical only	57	52	44	71
Combination of	37	34	17	27
None	7	6	1	2
Total	110	100	62	100

Fig. 1: CHANGES IN WEED DOMINANCE
AFTER CONTINUOUS HERBICIDE APPLICATION IN THE MUDA AREA

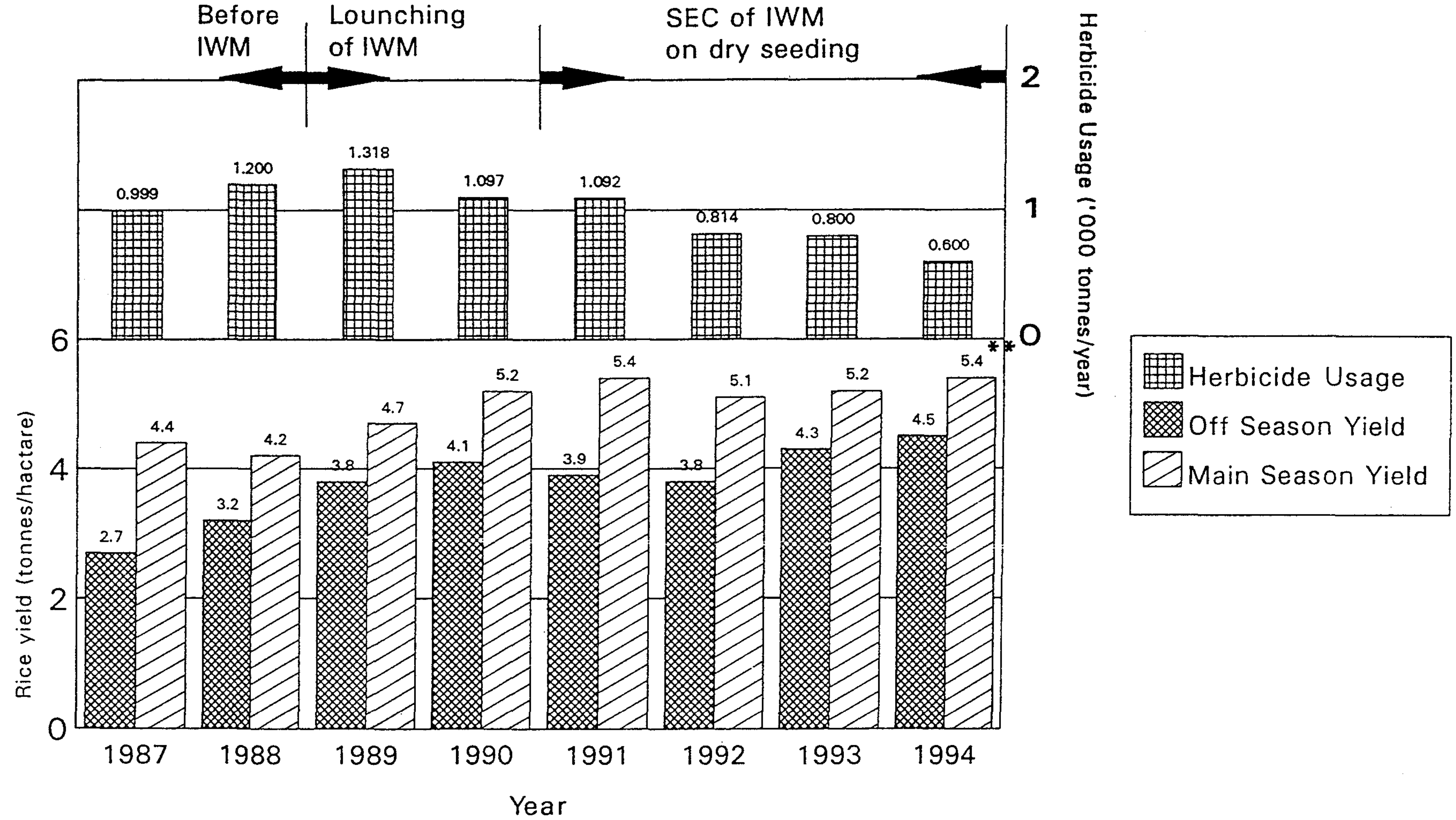


* Continuous application of pretilachlor + safener (0.5 kg ai/ha)
** Weed assessment at 50 - 55 DAS



* Continuous application of molinate (3.0 kg ai/ha)
** Weed assessment at 50 - 60 DAS

Fig.2: YIELD PERFORMANCE AND HERBICIDE USAGE IN THE MUDA AREA (1987 - 1994)



* IWM = Integrated Weed Management
** Yield for Main Season 1994 is estimation only.

LONGTERM DIRECTION OF HERBICIDE USE IN PADDY FIELDS IN KOREA

JA OCK GUH* AND YUN-JIN OH**

* College of Agriculture, Chonnam National University, Kwangju 500-757, Korea
** National Youngnam Agricultural Experiment Station, RDA, Milyang 627-130, Korea

Abstract : Due to rapid industrialization since the 1970s, farm labour has decreased and the amount of herbicide use has drastically increased. In the 1970s the annual herbicides of diphenylethers and acid amides were widely used, there by in the 1980s perennial weeds dominated in paddy fields. "One-shot herbicides", combinations of two or three herbicides including sulfonylureas, were used to control annual and perennial weeds at the same time by application during the growing season. Ideally, these combination products should maximize the synergistic effect of each herbicide so that the amount applied to a given area can be decreased. However, since weed species in a rice field may not need such broad coverage, the combination products are not always ideal in it. Thus, intensive use of these herbicides can actually increase the soil contamination in a long term. Especially in Korea, the sudden change in the cultural system from transplanting to direct seeding gives rice longer growing season in fields and induces weed species which become tolerant to combination herbicides. Under such conditions control of weeds connot be achieved with the existing combination products. To improve efficiency of rice herbicide use the following should be considered: ① re-establishment of crop-weed competitive relationship in different cultural systems (in relation to sequential application); ② restraint of imprudent use of one-shot herbicides and sequential application of herbicides: ③ development of reduced use technology to minmize environmental contamination: ④ rotation of herbicides with different modes of action: ⑤ development of specific herbicides for certain weeds: ⑥ development of foliar-applied herbicides: and ⑦ development of an herbicide use technology toward integrated weed management.
Key words : direct seeding rice, weed problem, one-shot herbicide, sequential application tanc-mix, IWMS, rotation application

I. Introduction

Rice in Korea is grown on 1.2M Ha. or 52% of total cropping acreage. Thus, rice is the single most important crop representing 43% of agricultural gross income of farmers with more than 115Kg of annual per capita consumption.

Rice production in Korea today is being placed in very difficult socio-economic situations due to rapid decrease in rural population, poor labor quality, high wages of rural society and shrinking to 3-D(difficult, danger, and dirty) agricultural works.

Self-sufficiency of rice had been one of nation's goals for decades until 1977 when it was achieved through breeding of high-yielding varieties and improved cultural practices. As the result of continuous national researching for technical innovations, the production of rice has been maintained above the level of self-sufficiency resulting in surplus availability particularly, during the last few years.

On the other hand, rice production in Korea today is faced with critical challenges due to ① oversupply of rice, ② changes of farm demographics to fewer and older farm population, and ③ weakness in competing with international rice market. In order to overcome those internal as well as external challenges, rice production in Korea will have to go through significant changes in cultural practices nowaday and in the next few years. Accordingly, an urgent goal is the reduction of production cost by improving of labor productivity in rice cultivation.

Until recent years, the most important target of rice culture was maximum yield, whereas in these days it was changed to economic yield that minimize the production cost.

Since 1990, Rural Development Administration(RDA) has introduced so-called "machine-transplanting of infant seedling(8 to 10 day-old)". More recently, direct-seeding and minimtill/no-till rice are under development to improve competitiveness of Korean rice in the open market. It will be an interesting task to identify key issues related to rice production in Korea in the future.

In comparing the productivity of labour and land, the land productivity of Korea is not significantly lower than that of California but the labour productivity of Korea is far below that of California. This is probably due to the condition of small-scaled farming, in which large machinery is not practicable and land is not adjusted for. Therefore, the situations should be improved and the cultural system should also be transferred to direct seeding method.

II. Review on the Changes of Rice Culture Systems

Machine transplanting was introduced in the late 1970s with 30-35 days old seedlings. Before hand, the conventional hand transplanting was used with 40-45 days old seedling. From the viewpoints of weed control, there were 2 major concerns; ① herbicidal phyto-toxicity increased as the age of seedling was younger and transplanting depth was shallower, and ② the infestation area by perennial weeds, typically *Sagittaria pygmaea, Cyperus serotinus, Eleocharis kuroguwai*, etc. were significantly increased.

New herbicides were screened for the younger rice seedling and one-shot herbicides with SU were successfully be introduced since 1983.

Machine transplanting has significantly increased during 1980s. And, the age of transplanted seedling was declined to be younger up to 8 days. Nowadays, it is estimated that more than 95% is transplanted by machines and more than 50% of the acreage is with 8 days old seedling.

In order to save labour for nursery beds, the new technology of using 8-day old seedling was introduced in 1990, instead of conventional 30-day old seedling. In the early days, herbicide phyto-toxicity was a serious concern with 8-day old seedling.

However, the 8-day old seedlings have shown much stronger tolerance to most herbicides than 30-day old seedlings, and the reason was found to be the active endosperm attached to the 8-day old seedling at the time of transplanting.

On the other hand, direct-seeding practice has been be introduced since 1991. Follows are the trend of seeded acreage during the last 4 years.

The most crititcal factors for success of direct-seeding are ① weed control in early growing stage and ② stable maturity as the growing period is longer than in transplanting.

In direct seeding under dry paddy condition, an effective weed control is the most serious problem. Since it has maintained under dry condition up to 30 days after seeding, both lowland and upland weed species will exist at the same time. Even though fields would be irrigated after seedling stand of the rice plant, water is easily leaching down from the soil surface. This may provide more chance to germinate the weed species. Also, dry paddy condition also result in weed shift to annual grass weeds such as *Echinochloa crusgalli, Oryza sativa spp. spontanes, Leptochloa chinensis, Setaria viridus, Eleusine indica, Digitaria sanguinalis*, etc.

The practical weeding method in direct seeding under flooded condition is a similar to the transplanted rice cultivation except seeding procedure. There are two kinds of different seeding methods under flooded condition, which are such as water soil surface broadcasting and water subsoil drill seeding. In case of water soil surface broadcasting, the rice plant during reproductive and ripening stage might be easily lodged by the wind or typhoon while water subsoil drill seeding would not be as shown in Table 4.

Under the flooded direct-seeding, effective weed control is still a challenge due to phyto-toxicity of herbicides. Tank-mixes of propanil with butachlor and pendimethalin or being developed for weed control at early growth stage. In order to overcome the issue of extended growth period, the direct-seeding is currently being recommended in southern area. In longer term, development of early maturing varieties is required.

It is said that Korea is in a transition stage from transplanting to direct-seeding. The future planting system largely depend on successful introduction of direct-seeding under farmer's condition. The gov't has a very strong desire to expand the acreage of direct-seeding in future as it provides an opportunity for more economic rice production in Korea. Critical factors for successful direct-seeding may be;

- Establishment of efficient seeding method.
- Prevention of lodging.
- Establishment of seedling stand under flooded direct-seeding
- Establishment of effective weed control programs.
- Development of new rice varieties suitable for direct-seeding; lodging resistance and shorter growing period.

Actually, Korea has the potentialties in acreages to increase the direct seeding systems by region as shown in Table 2.

III. Review on Major Problem Weeds and Weed Control Systems

There is a great difference in weed occurrence among different rice growing systems.

In hand translanting major dominant weed species are *Echinochloa crusgalli, Scirpus juncoides, Monochoria vaginalis, Aneilema japonica,* and *Ludwigia prostrata* as annual weeds while as perennial weed species *Eleocharis kuroguwai* and *Cyperus serotinus* are predominant. On the other hand, there are more predominant annuals including. *Scirpus juncoides, Echinochloa crusgalli, Cyperus difformis, Aneilema japonica, Monochoria vaginalis, Polygonum hydropiper, Ludwigia prostrata* and *Rotala indica,* and perennials such as *Eleocharis kuroguwai* and *Cyperus serotinus* are dominant in transplanted rice with semi-adult seedling.

In the rice field transplanted with infant seedling, dominant weed species are *Echinochloa crusgalli, Cyperus difformis, Monochoria vaginalis, Aneilema japonica, Persicaria hydropiper, Lindernia procumbens* as annual weeds, and also *Eleocharis kuroguwai* and *Cyperus serotinus* of perennial weeds are predominant like the field transplanted with semi-adult seedling cultivation.

Unlike in transplanted rice, dominant weed species in direct seeding would be different in lowland rice field.

In general, *Alopecurus aequalis, Echinochloa crusgalli, Cyperus difformis, Monochoria vaginalis, Aneilema japonica, Persicaria hydropiper, Lindernia procumbens, Rotala indica, Persicaria hydropiper, Ludwigia prostrata, Aeschynomene indica, Eragrostis multicaulis,* and *Centipeda minima* as annuals, and *Eleocharis kuroguwai* and *Cyperus serotinus* as perennial weeds were dominant in water seeded rice.

In particular, dominant weed species are quite different in direct seeding under dry condition. There are predominant weed species such as *Alopecurus aequalis, Cardamine flexuosa, Stellaria alsine, Mazus miquelii, Echinochloa cursgalli, Scirpus juncoides, Cyperus difformis, Lindernia procumbens, Aneilema japonica, Rotala indica, Persicaria hydropiper, Ludwigia prostrata, Lindernia angustifolia, Centipeda minima, Aeschynomene indica, Eragrostis multicaulis,* and *Digitaria sanguinalis* as annual weeds, and also perennial weed species like *Eleocharis kuroguwai* and *Cyperus serotinus* are dominant.

Ⅳ. Evaluation of Weed Control Systems
-Based on Herbicide Use-

A. Reestablishment for critical period of competition according to change of rice culture systems

Direct seeding method will undoubtly result in drasic increment of weed growth compared with transplanting method, and also will shift to the troublesome weed flora. The important troublesome weeds in direct seeded rice will be *Echinochloa* spp., *Digitaria* spp., annual *Cyperus* spp., *Leptochloa* spp. and *Setaria* spp., etc. Addition to that, some annual broadleaf weeds such as *Aeschynomene* spp. which is not an important weed in transplanted rice may be an important weed, and flooded direct seeded rice will be suppressed by occurrence of algae. Therefore, new integrated weed management concept including reestablishment of critical period concept in weed competition due to shifting of cultural methods might be needed to approach an effective weed control in direct seeded rice filds.

The Figures 1 show the critical period of compettition newly established under different cultural systems of rice in Honam district.

The critical period of competition in convertional hand-transplanting is not clear. In this system the critical competition with weeds can be avoided either by herbicide application at 4 weeks or 8 weeks after transplanting. Thus, satistactory control of weeds can be acheived by treatment as soil application or foliar application. The similar trend was observed in transplanting with young seedlings(8-day old), in which weed control can be satistactorly achieved by a treatment at either 5 or 7 weeks after transplanting.

However, in water seeded rice weed control is required from 5 weeks after seeding and the required critical periodc of weed-free is about 7 weeks from seeding. This indicates that the period of weed control is longer; thus, one application of herbicide with one-shot or foliar application is not enough to control weeds satisfactorily, therefore, sequention applicatic is needed to control weeds in water-seeded rice.

In dry seeded rice weed occurence including upland weeds is much more severe. Therefore, it is necessary to apply a herbicide one time during the first dry period and two times after flooding.

B. Appraisal of one-shot herbicides

One-shot herbicides are premixtures with more than two herbicides which have different target weeds. They are designed to obtain satisfactory control of weeds by one application during the whole season. However, there are two purposes to once use of one-shot herbicides. First, they should be designed to control the broed spectrum of weeds by applying smaller amount of each compound because they must have synergistic or additiue effect. The second point is to save labours by reducing the number of application doing in the season, though there is no additive or synergistic effects expected. Most of one-shot herbicides or premixtures in Korea are desigsned to save labours.

In Korea the herbicides registered in rice 1994 are 54 products, of which 12 products are single and 42 products are double or triple combination. During the past 10 years the combination products are onesidely registered.

The products registered in dry seeded use are butachlor, Giljabi(propanil + pendimethalin), Satanil(propanil + thiobencarb), Momanna(Propanil + molinate), and those in water seded rice are Dubaenon(dithiopyr + bensulfuron), Ddazi (pretilachlor + fenclorm).

Most of one-shot herbicides are not adopted to direct seeded rice because of the time of weed emergence, different weed spectrum, and crop growth stages. But in the near future the herbicides for sequential application may be developed for direct seeded rice. In general most of one-shot herbicides have weed spectrum that are overapped by each herbicides, except for barnyardgrass(*Echinochloa crus-galli.*). In addition, one-shot herbicides are well coincided with farmers convenience in terms of application time for most annual and perennial weeds expected from the overall situations.

Unlikely, in survey of weed occurence from 111 farmers fields, perennial weeds were found to be problems in only 35 fields(31%). In other words, the fields with problems of annual weeds were represented 69%, suggesting that one-shot herbicides may not be necessary in some fields and that application of one-shot herbicides induced more impact of herbicides increase of soil residues and contamination possibiity, there by affecting economic loss to farmers. In the United States, tank-mix treatments are widely used to broaden the spectrum of weed control, but in Asia(Korea), one-shot herbicides cause same problems because they are used for convenience and laboar saving. Thus, tankmix treatments should be reconmended for farmers practices.

V. Longterm Tasks for Sequential Application Systerm of Herbicide
- for large-scale farming of direct seeding -

The merits in use of herbicides are as follows [Table 6] ;

In order to utilize rationally the merits of herbicide use, the herbicides to be developed should be met with the following conditions [Table 7].

From these points of view the tasks in large-scale farming in Korea are to be suggested as follows.

A. Development of herbicides for control of resistant weeds

As rice culture system is transferved from hand and machine transplanting to direct seeding, the distribution ratio of annual grass and brodaleaf weeds has been increasing. Especially, the dominant weeds in water seeded rice are *Alopecurus aequalis*, *Aneilema japonica*, *Aeschynomene indica*, *Leptochloa* spp., *Lindernia procumbens*, *Centipeda minima and Eragrostis multicaulis*, and those in dry seeded rice are *Alopeculus aequalis*, *Cardamine flexuosa*, Mazus miquelii, as winter annual weeds, and most noxious trobblesone weeds as in water seeded rice.

Most of weeds dominant in direct seeding are tolerant to the existing rice herbicide.

B. Development of special formulation

Most of rice herbicides are formulated in granular types, becomse of small rice acreage/household and lack of application equipment. However, development of effective spreader or new formulation types is requested for lage-scale framing in the future.

C. Development of foliar applied herbicides

Most of rice herbicides are soil applied before or right after weed emergence. They are not enough to use in large-scale terming in fams of application time and application quantity.

Due to short labour, and lack of application equipment and mechines, foliar applied herbicides with wide application window are needed to develop under Korea conditions in which application time is concentrated in a short period of time after transplanting or seeding.

D. Stability of herbicide activity and selectivity to water and soil

In large-scale farming, it is not easy to consistently control the cultural managements such as irrigation, drainage, and cultivations. Therefore, weed species, emergence and growth characteristics are different accordingly, inducing the differences in activity and selectivity of herbicides applied.

E. Necessity to develop the technology of sequential treatment with single product and of tank-mix treatment

The critical period of weed competition in large-scaled direct seeding is longer, so the sequential treatment is required. But the dominance of a certain weed species is increased with succession of weeds, so a system of sequential treatment is required with a herbicide having broad spectrum of control and with a special herbicide controlling new comers.

When various species emerge at the same time, satisfactory efficacy is not expected by application of single product, so that minimum number of product and rate will be effective.

F. Technology avoiding consecutive use of a certain herbicide

Farmers tend to select and apply a certain herbicide continuously became they do not know about herbicides and weed species well.

Continuous use of one herbicide causes increased residues in soil, restriction of certain groups of microorganisms in soil, and increased dominance of resistant weed species. Show(1982) suggested the rotation model for herbicides and crops, though it is not in case of rice.

G. Development of Intrgrated Weed Management Systems(IWMS) Technology

Chemical weed control has significantly increased yields, reduced weed seeds in soil, reduced tillage, improved harvesting efficiency, reduced labor requirements, and dramatically increased net farm profits without damage to the biological, chemical, or physical properties of the soil ; without reducing the productivity of the soil ; and without causing undesirable shifts in weed populations(1).

For those technologies, every fundamental cultural practices should be kept in quiet a level of the best conditions. Advances in and cost of weed-control technology must be assessed as a part of our total farm-management production and protection technology, which includes follows.

Those production and protection practices have been integrated into high-yielding agroecsystems that are compatible with a quality environment. They have had far-reaching benefits(2,4).

In conclusion, use of herbicides should be minimized for stability and safety of ecosystem, although herbicides are compelled to use for farmer's economic points.

References

1. Shaw, W. C. 1982. Integrated Weed Management Systems Technology for Pest Management. Weed Sci. 30-Suppl. 1:2-12.
2. Ennis, W.B., Jr. W.C. Shaw, L.L. Danielson, D.L. Klingman, and F.L. Timmons. 1963. Impact of Chemical Weed Contrl on farm Management Practices. Adv. Agron. 15:161-210.
3. Ennis, W.B., Jr., W.M. Dowler, and W.Klassen. 1975. Crop protection to increase food supplies. Sci. 188:593-598.
4. Shaw, W.C. 1974. Total farm weed control concepts for pest management. Agric. Res. Serv., U.S. D. A. Beltsville, MD:15.
5. Guh, J.O. 1993. Weed control Practices for Direct Seeding Rice Culture Systems. Chonnam Univ. Educ. Bull.
6.Agr. Chem. Ind. Assoc. 1995. Focus on the development of Lower Toxic and enviroment conservable pesticides. Pesticide Intormation. 124:22-27, 50-52.
7. Lee, Y.I., Y.J. Oh, E.J. Lee, and M. N. Chung. 1993. Evaluation of Rice Market Opportnnity in Kores. Private Communications.
8. Agr. Chem. Ind. Assoc. 1994. Manualbook of Pesticide Use. pp.640.
9. Agr. Chem. Ind. Assoc. 1993. Agrochemical Year Book. pp.508.

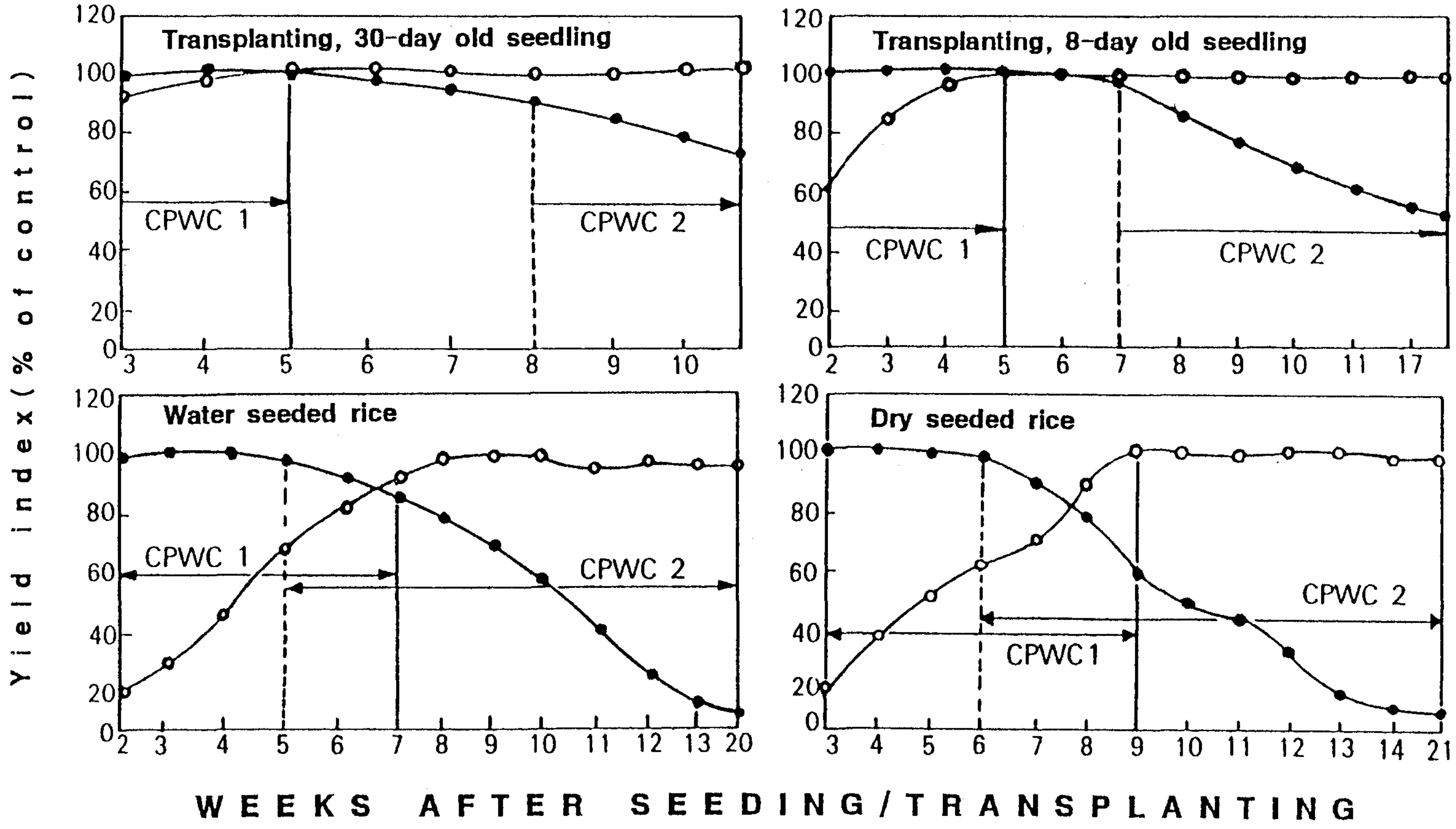


Fig. 1. Critical period of weed competition(CPWC). ○—○ : weed-free, ●—● : weed competition

Table 1. Recent trend of direct-seeding acreage of rice in Korea

	Direct Seeding(Ha.)	
	Dry	Flooded
1991	259	0
1992	1,710	1,010
1993	3,550	4,020
1994	35,336	37,469
(1995)	(50,000)	(70,000)

Table 2. Comparison of regional potential acreage in direct seeding rice culture RDA('93)

Regions	Total acreage	Direct seeding potentials (Thousant Ha)			
		Sub-total	Dry C.	Flooded C.	D+F.C
Total	1,268	703	162	169	372
Central	315	153	62	22	69
S. Western	564	361	87	96	178
S. Eastern	389	189	13	51	125

Table 3. Changes of dominant weed species in lowland rice field

Year	Order of dominance				
	1st	2nd	3rd	4th	5th
1971	R. indica	E. acicularis	M. vaginalis	C. difformis	E. crusgalli
1981	M. vaginalis	S. pygmaea	S. trifolia	P. distinctus	C. serotinus
1992	E. kuroguwai	S. trifolia	E. crusgalli	C. serotinus	M. vaginalis

Table 4. Comparison of major weed emergence by rice planting systems

Planting systems	Individuals (No/m²)	Dry W (g/m²)	No. species	Diversity	Yield reducton(%)
Adult seedling 1 Hand T.	269	15.7	7	0.631	15
30 days seedling 1 Machin T.	295	58.8	10	0.687	27
10 days seedling 1 Machin T.	625	164.8	10	0.657	33
Direct seeding/Flooded	840	751.6	15	0.793	50
Direct seeding/Dry	1,090	776.1	20	0.865	85

Table 5. Survey of weed occurence from farmers fields (Chonnam, random 111 fields,1994)

Weed occurence(coverage %)	Fields(%)	Sub-total
Less(< 5%)	26(23.4)	26(23.4)
Annuals mostly(5~10%)	37(33.3)	50(45.0)
Annuals mostly(10~30%)	11(9.9)	
Annuals mostly(> 30%)	2(1.8)	
Annuals and Perennials mixed(5~10%)	23(20.7)	31(27.9)
Annuals and Perennials mixed(10~30%)	7(6.3)	
Annuals and Perennials mixed(> 30%)	1(0.9)	
Perennials mostly(5~10%)	3(2.8)	4(3.7)
Perennials mostly(10~30%)	1(0.9)	
Perennials mostly(> 30%)	-(-)	
Total	111(100)	111(100)

Table 6. Advantages in herbicide use among other weeding methods

- Selective application on a specific crop
- Control of weeding timing
- Energy save → increase cropping and frequency density
- Lower the physical damage on crops → application possibility
- Weeding possibility in any sites(Forest, water, etc.)
- Lower the soil interferance → rapid and when-ever application
- Some what additionally, growth regulating effects on crops

Table 7. Requisities of Herbicide

- Low toxicity(Safety in environment, men and animals,
- High selectivity(Crop damage ↓, Weeding efficacy ↑)
- High environmental stability
- Lower price (otherwise low cost)
- Easy handling in storage, transport, application and production
- Others

Table 8. Effect of labour saving by formulation types of rice herbicides

	SC (5 ℓ/Ha)	GR (30Kg/Ha)
Application method	irrigation channel	hand spread
Application hour/ha	50 min	300 min
Bioactivity(%)	92	95
Labour saving(%)	83	0

Table 9. Features of existing soil-applied herbicides (Necessity of developing foliar-applied herbicides)

1. inconsist and incomplete efficacy of soil-applied herbicides
   ← great effect of soil and water management
   → increased competition with regrown weeds
2. less possibility of applying at proper time
   ← large-scale timiming, difficulty in mechanization, uniqueness of crop growth stage
3. difficulty in consistent prescription (in case of direct seeding)
   → changing characters of weed emegerence time, year by year, and region by region
4. difficulty in minimizing labour power, herbicide cost, and in herbicide selection
   → Selective application in optimum rates and herbicide (in case of foliar-applied herbicides)
5. usage in sequential application
   → most soil applied, pre-and early post-emergence pre-mixed herbicides
6. difficulty in controlling weeds in water channel and levees
   → minimizing contamination of water and soil by use of foliar applied herbicides.

Table 10. Model 1 : Rotation of different herbicides on the same crop

Year	Crop sequence	Chemical weed control treatments		
		Preplanting	Preemergence	Postemergence
Fist	Corn	EPTC	Atrazine	2,4-D
Second	Corn	Atrazine+clachlor	Atrazine+propachlor	Linuron
Third	Corn	Cyanazine+butylate	Propachlor	Dicamba
Fourth	Soybeans	Trifluralin	Metribuzine	Bentazon+2,4-DB

Table 11. Model 2 : Rotation of different herbicides on all crops

Year	Crop sequence	Chemical weed control treatments		
		Preplanting	Preemergence	Postemergence
Fist	Corn	Atrazine+alachlor	Atrazine+propachlor	2,4-D
Second	Peanuts	Vernolate	Alachlor+dimoseb	2,4-DB
Third	Cotton	Trifluralin	Fluometuron	MSMA+methazole
Fourth	Soybeans	Fluchloralin	Metribuzin+alachlor	Bentazon+2,4-DB

Table 12. Advantages of herbicides when used in IWMS(1,3)

- a wide array of herbicides is available to control most weeds at practical costs
- herbicides act quickly ;and are effective against dense weed populations
- reliable equipment is widely available to apply herbicides
- herbicides permit the individual grower to protect his crops irrespective of any action taken by his neighbors
- most herbicides are used selectively
- herbicides are dependable and essential to the effective use of IWMS

Table 13. Necessity of I WMS as the present question

- new species(resistant and new species) to be managed in order to reduce development requirement of new herbicides
- use of ecological and physical methods for control of perennial weeds in order to solve the problems of one-shot herbicides
- introduction of rotation system of crops and herbicides in order to avoid the problems of consecutive application
- maximum efficiency of herbicide efficacy by gradually reducing weed emergence and number

Technical innovation in herbicide use.

○Michiaki Kamoi, Koji Noritake
Researh Institute of The Japan Association for
Advancement of Phyto-Regulators (JAPR)

According to the statistical research as shown in Fig.1, the weeding labor time in paddy rice culture in Japan in 1992 was only two hours per 0.1 hectare, which is less than 4% of 50.6 hours with the times in the previous introduction of paddy rice herbicides, and is corresponding to about 5% of 41.1 hours of total labor time in the rice culture in 1992.

This situation resuls from the development of new candidate and the improvement of formulation as paddy rice herbicides, and in addition the rational spreading of these herbicides.

Especially after 1983, the weeding labor time has been saved owing to simplifying application methods, which are the reduction of application frequency by the development and introduction of "the one shot herbicide", and the reduction of application amount from 3kg/0.1ha agent to 1kg/0.1ha agent as well as the development of the flowable formulation. Now, herbicides are able to apply handily from levees into paddy fields.

Since 1991, the Japan Association for Advancement of Phyto-Regulators (JAPR) has carried out basic research on the throw-in type formulation (so called "Jumbo Herbicide", JH) to develop the safety and easy application method and to save application labor for the rice production cost to reduce, and besides toward the age of older farmers engaged in rice production.

At first, JH agents have been examined in an attempt to treat 20 packages of each 50g/0.1ha from levees into paddy fields without machine used.

From the results obtained, two kinds of JH were already filed for the registration in 1994. These JH agents are started on sale in 1995. And at present, thirty products are being evaluated as a JH agent through the JAPR.

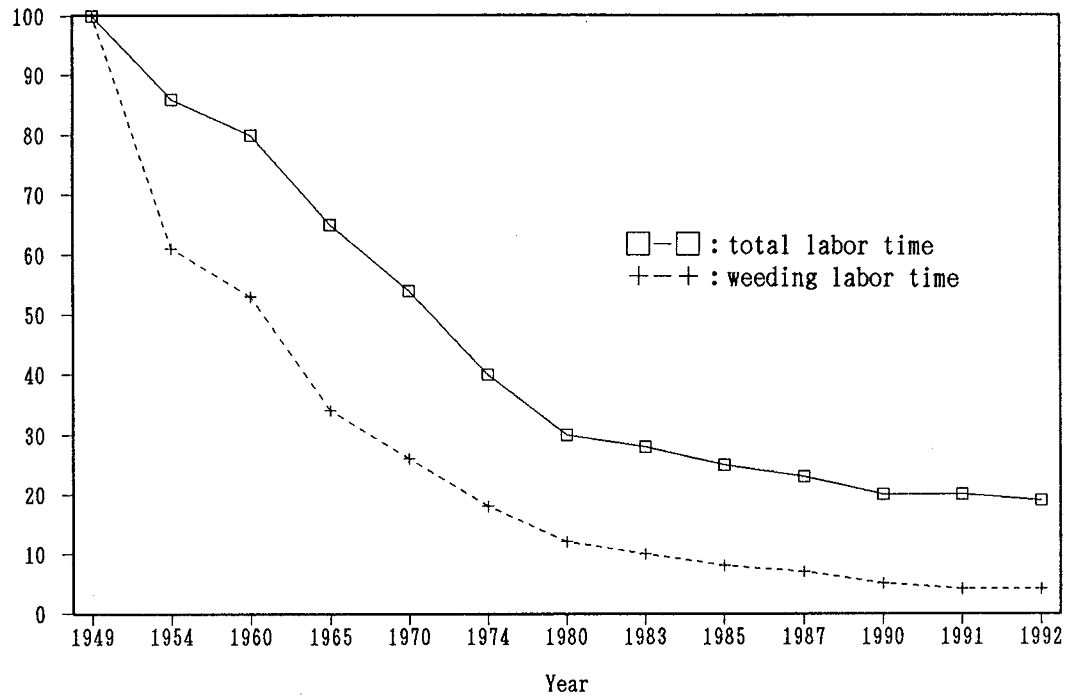


Fig. 1 The change of weeding labor time in paddy rice culture (against 1949)

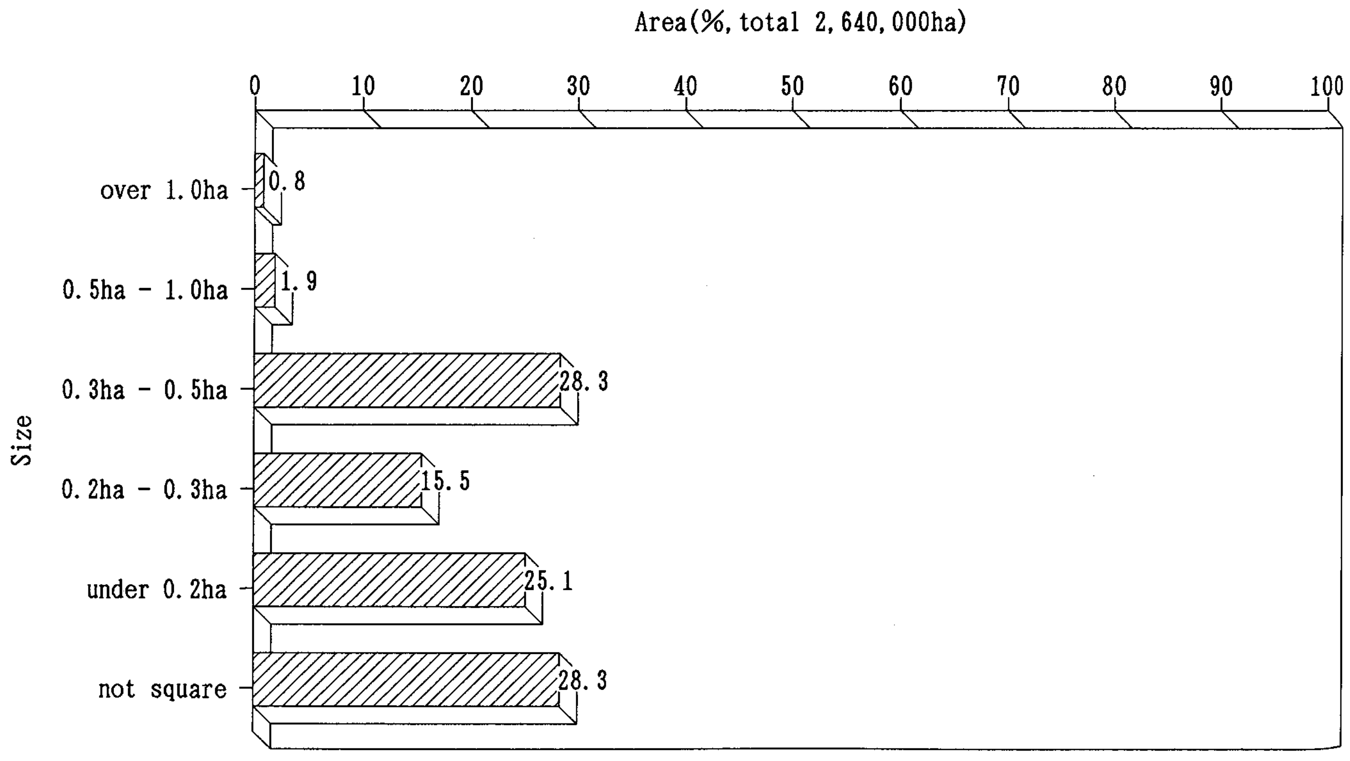


Fig. 2 Present situation of compositin on paddy field in Japan

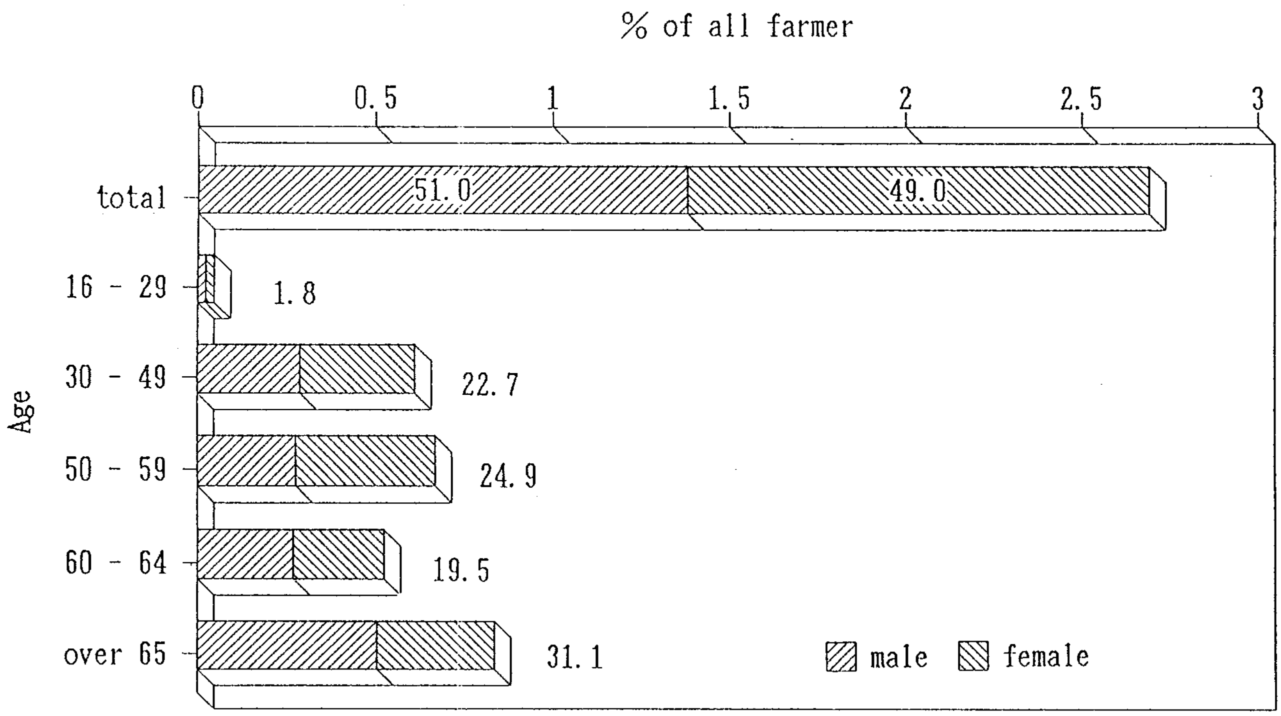


Fig. 3 Present situation of age component in farmers in Japan

Table 1 Comparison of labour burden between throw-in type formulation (Jumbo herbicide, JH) application by hands (JH) and conventional granule application by back-pack power distributor (PD) from levees of a paddy field.

	Work efficiency-1 work time per 0.1 ha(min./0.1ha)		Work efficiency-2 work area per min. (0.01 ha/min.)		Work intencity-1 heart rate (heart rate/min.)		Work intencity-2 energy metabolic rate(RMR*)		Work intencity-3 energy consumption per 0.1ha(kcal/0.1ha)	
	JH	PD	JH	PD	JH	PD	JH	PD	JH	PD
Male A (62 years old)	1.5	1.9	6.7	5.3	119	136	3.8	4.8	7.3	11.0
Male B (38 years old)	1.3	1.7	8.0	6.0	113	135	2.8	4.2	5.9	10.3

* RMR is a parameter of work intencity to indicate how much energy is consumed in work with the metabolic rate and calculated by the following equation.

$$RMR = \frac{\text{metabolic rate at work} - \text{metabolic rate at rest}}{\text{base metabolic rate}}$$

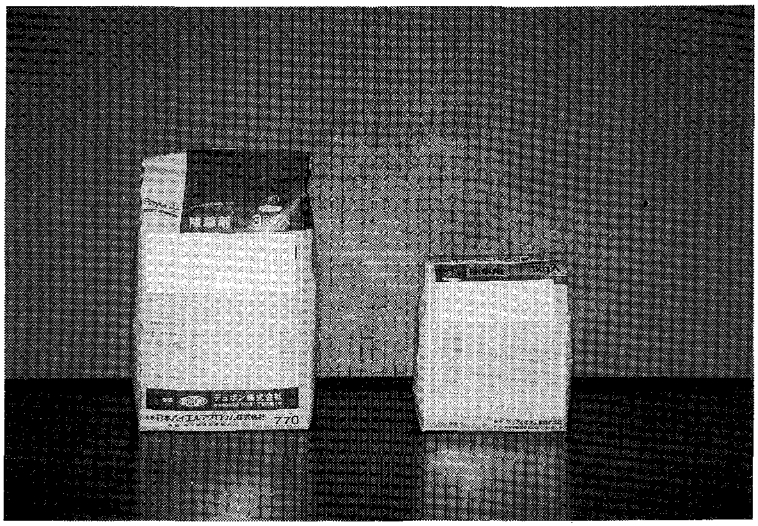


Fig. 4 3kg/0.1ha Granule (left). 1kg/0.1ha Granule (right).

Fig. 5 Granule application by back-pack power distribution from levees.

Fig. 6 Granule application by power duster with boom type blow head.

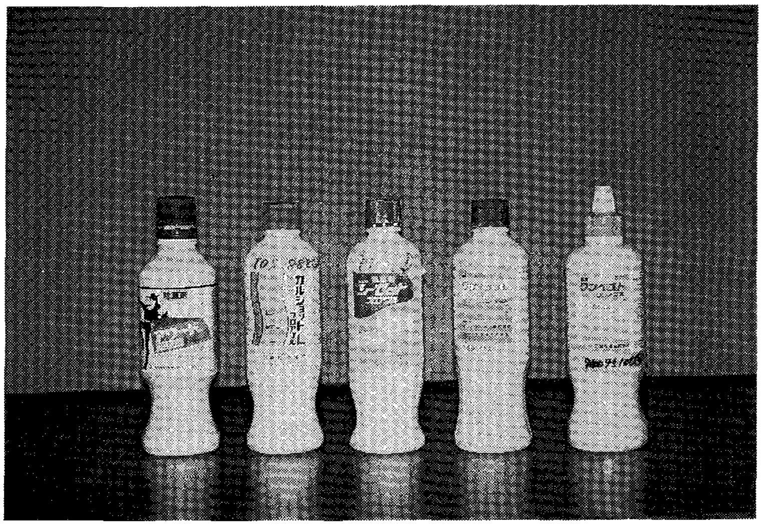


Fig. 7 Several flowables of one-shot herbicide.

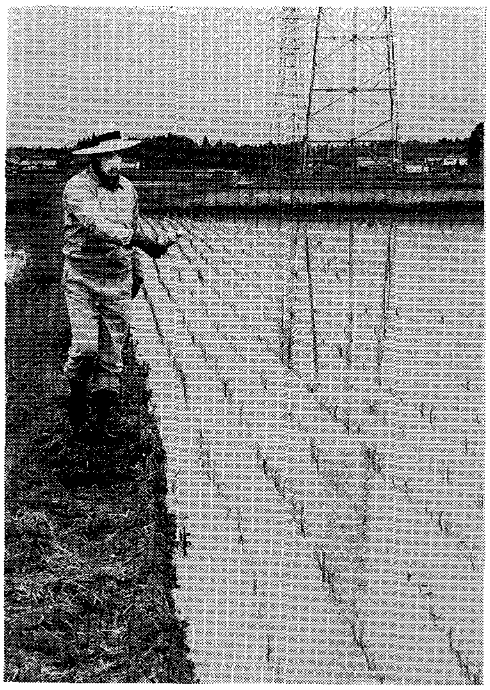


Fig. 8 Flowable application from levees by hands.

Fig. 9 Flowable application at irrigation inlet.

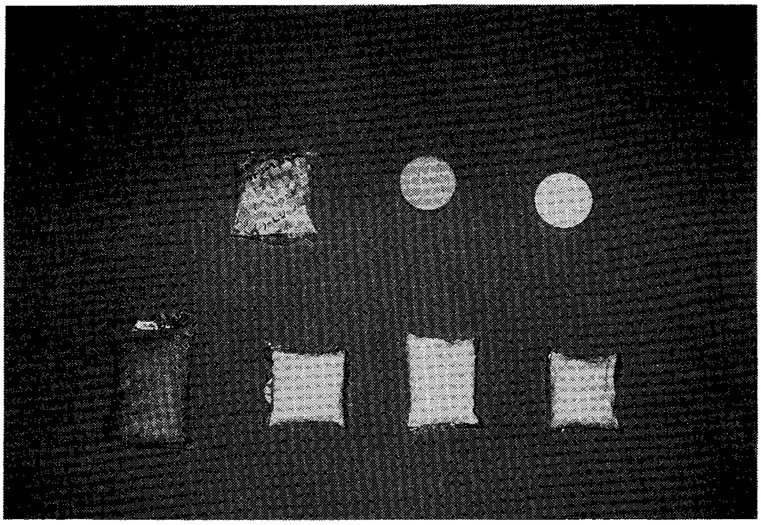


Fig. 10 Several throw-in type formulations (so called "Jumbo Herbicide")

Fig. 11 "Jumbo Herbicide" application from levees by hands.

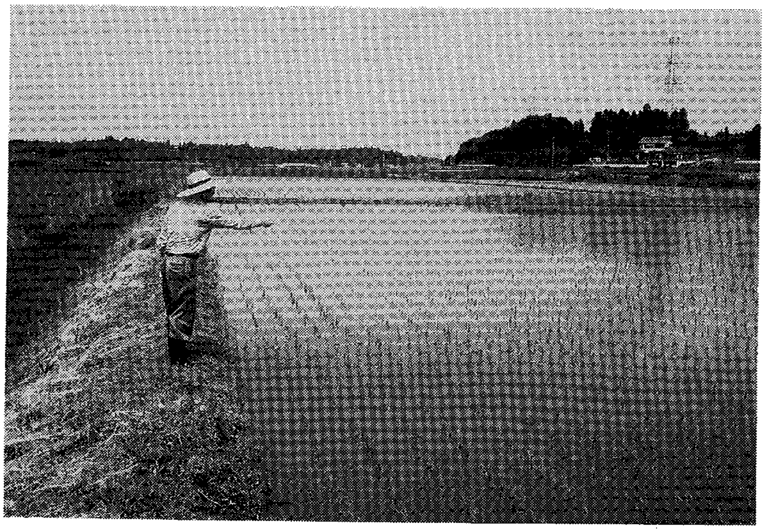


Fig. 12 "Jumbo Herbicide" application from levees by hands.

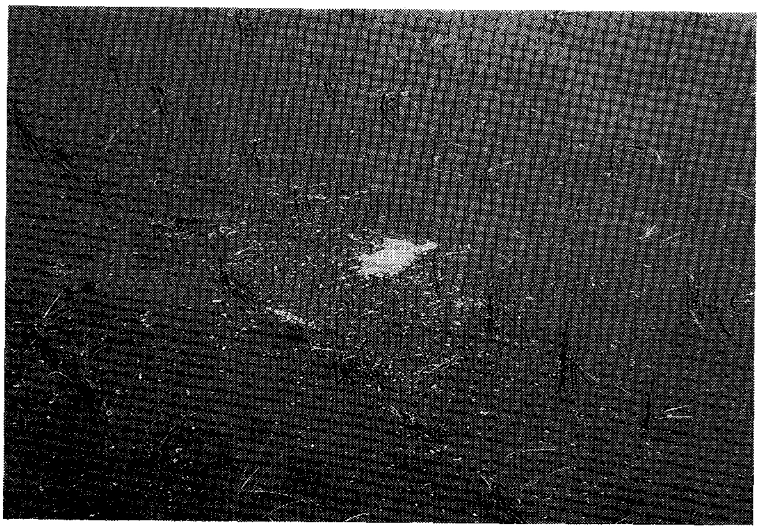


Fig. 13 "Jumbo Herbicide" diffusion from a water soluble package.

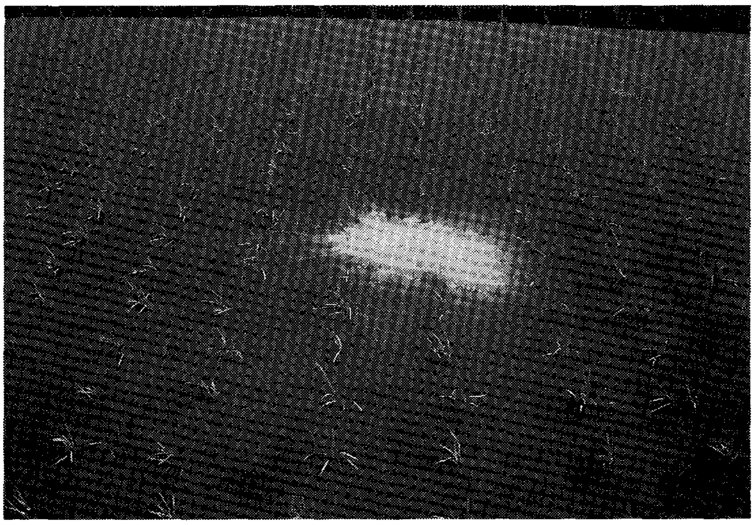


Fig. 14 "Jumbo Herbicide" diffusion from bubbling tablet.

ALLELOPATHIC COMPOUNDS AS NATURALLY OCCURRING HERBICIDES

Chang-Hung Chou
Institute of Botany, Academia Sinica, Taipei, Taiwan 115, Republic of China

Abstract Allelopathy is the result of biochemical interactions between plants. It is caused by toxic chemicals which are released by the plant through volatilization, leaching, and root exudation or produced during the decomposition of plant residues in the soil. Phytotoxins, including fatty acids, phenolics, flavonoids, terpenoids, and alkaloids, have been found in plants and soils from different habitats around the world. Since 1972, we have reported that allelopathic metabolites are released from woody plants, such as *Phyllostachys edulis, Leucaena leucocephala, Vitex negundo*, and *Delonix regia*, to suppress the growth of understory species, causing a significant reduction of biomass and a low diversity of understory plants. The formation of dominance of the tree species mentioned above is due primarily to the phytotoxic effects of metabolites released from plant parts, such as leaves, flowers, and twigs, and the decomposition of fallen litter. A pasture grass-forest intercropping system was established by introducting kikuyu grass into a deforested region where coniferous trees or hardwood plants were allowed to regenerate. Because of the allelopathic potential of the kikuyu grass, weeds grown in the deforested land were suppressed by the grass six months after the grass was planted; the growth of regenerated forest plants was not suppressed, however, but was stimulated. This example clearly demonstrated that allelopathic compounds can be used as natural herbicides to control weed growth in agricultural practice. This will reduce the use of synthetic herbicide, avoid agrochemical runoff, and reduce expensive labor costs.

Key words. Allelopathy, phytotoxin, phenolics, flavonoid, alkaloids, sustainable agriculture, allelochemicals

Introduction

Secondary plant metabolites included a variety of compounds which released from plants into the environment often attract or repel, nourish or poison other organisms. Yang and Tang (1988) made an extensive review of plants used for pest control as described in *Shengnoon Ben Tsao Jing* in 25-220 A.D.in China. They found 267 plants containing pesticidal activity, many of them also exhibiting allelopathic potential. In 1832, De Candolle, a Swiss botanist, suggested that the soil sickness problem in agriculture might be due to exudates of crop plants (Rice, 1984). Whittaker and Feeny (1971) clarified that "chemical agents are of major significance in adaptation of species and organiation of communities". Since then, secondary metabolites have no longer been regarded as metabolic waste, but play an important role in plant adaptation and plant-insect coevolution (Chou and Waller, 1989; Ehrlich and Raven, 1965; Harborne, 1977). Allelopathy, a detrimental biochemical interaction between plants, plays directly or indirectly roles in mechanism of plant dominance, succession, and climax, and in regulation of crop productivity, genetic diversity, and ecosystem stability (Muller, 1966, Rice, 1984, Chou and Waller, 1989, Chou, 1993). For example, the compounds produced from California chaparral vegetation, such as *Salvia leucophylla*, and *Artostaphylos glandulosa* var. *zacaensis* (Muller, 1966; Muller and Chou, 1972), suppress the growth of its understory plants or nearby. The compounds are released into the environment by means of four ecological processes: volatilization, leaching, decomposition of plant residues in soil, and root exudation.

In past decades, agricultural practice has been drastically changed by applying an increased amount of fertilizers and agrochemicals, such as herbicide, fungicide, and pesticide into fields. The continuous use of agrochemicals in farm would cause severe environmental problems, such as losing efficiency of nitrogen fixation in soil, breaking the balance of soil microorganism, causing residual effect of agrochemicals, forming eutrophic water reservior, or leading to water pollution. As a result of long-term application of agrochemicals into the fields, certain dominant soil microorganisms will form, resulting in a pathogenic effect on crop growth (Patrick, 1971; Wu et al., 1976a and 1976b). A concept of sustainable agriculture, which implies organic, regenerative, biodynamic, intensive, low-input and resource-conserving has been much emphasized since 1980 (Francis and Sahs, 1986). Alternate ways of agricultural practices, such as organic farming, biological control, and crop rotation were recommended to solve the problem. In biological control, many natural plant growth regulators, such as agrostemin, can be used to weed control (Gajic and Nikocevic, 1973). Other allelochemicals were also used as fungicides, insecticides, and nematodicides (Rice, 1984; Waller, 1987; Rizvi and Rizvi, 1992), and were less than man-made agrochemicals to damage the global ecosystem. It makes efficient use of resources internal to the farm, relies on a minimum of purchased inputs, and minimizes the influence of agricultural practices beyond the farm boundaries (Chang, 1992; Gliessman, 1986). Putnam and Duke (1974) selected for allelopathic activity when breeding weed-controlling cultivars of cucumbers. Since 1972, Chou and co-workers have performed experiments in elucidating the role of allelopathy in agroecosystem in Taiwan and found many potential allelochemicals useful for agriculture practice (Chou, 1992). This paper is thus focused on allelopathic compounds isolated from local vegetation with the potential of prospective herbicides.

Secondary Metabolites as Potential Naturally Occurring Herbicides

Many secondary plant metabolites, such as phenolics, flavonoids, alkaloids, terpenoids, and cyanogenic glycosides, have often attracted scientists, particularly organic chemists, to the study of their satructure, biosynthesis, and natural distribution, but not to that of function until Frenkel (1959) and Whittaker and Feeny (1971) pointed out the important functions of the secondary metabolites in plants and in ecosystems. Waller and Nowacki (1975) note that plants produced high levels of alkaloids which are toxic to many organisms when the plants grew in soil poor in nitrogen. In addition, Koeppe et al. (1976) found that significantly higher amounts of allelopathic substances were also produced when plants grew in phosphorus-deficient soil. There is evidence that the secondary plant metabolites are often stored in vacuoles or in intercellular space when they are not used. The compounds are released into the environment by means of four ecological processes mentioned earlier (Chou, 1989). Based on the nature of allelopathic compounds isolated from each specific plant, the compounds are grouped into phenolics, flavonoids, and alkaloids described below.

Phenolic compounds

A unique pattern of weed exclusion by bamboo vegetation is often found on many hillsides of mountains at elevations below 1500 m in Taiwan. Founteen bamboo species were selected for evaluation of allelopathic potential. Among 14 bamboo species, *Sinocalamus latiflorus* showed the highest phytotoxicity, and *Bambusa oldhami, B. pachinensis, B. ventricosa, Phyllostachys edulis*, and *P. makinoi* revealed significant phytotoxicity (Chou and Hou, 1981; Chou and Yang, 1982). The allelopathic substances isolated from the bamboo leaves and their soil were identified as phenolic acids, namely, *o*-hydroxyphenylacetic, *p*-coumaric, *p*-hydroxybenzoic, ferulic, vanillic, and syringic acids (Table 1 and Figure 1). Most of these phytotoxic phenolics are also distributed in 12 subtropical grasses (Table 1) (Chou and Young, 1975), and in *Miscanthus* species (Chou and Chung, 1974; Chou and Lee, 1991).

Moreover, Chou and Chen (1976) also evaluated allelopathic potential of 25 woody species commonly occurring in northern Taiwan, 5 major compounds same as the compounds mentioned were present in leaves and litter of the plants.

In leguminous plantations of *Leucaena leucocephala*, there is an absence of understory growth other than itself. This is due primarily to the phytotoxins, including eight phenolic acids, namely gallic, protocatechuic, *p*-hydroxybenzoic, *p*-hydroxyphenylacetic, vanillic, caffeic, *p*-hydroxycinnamic and ferulic acids released from its leaves and litter (Table 1 and Figure 1). The compounds can suppress the growth of many weeds and forest species, such as *Acacia confusa, Ageratum conzoides, Liquidambar formosana, Casuarina glauca, Mimosa pudica,* and *Alnus formosana* (Chou and Kuo, 1987).

Flavonoids

Vitex negundo a dominant coastal vegetation, is widely distributed in the southern parts of Taiwan. Chou and Yao (1983) found that the biomass and density of its associated understory is less than that in adjacent pasture. Field results showed that, compared to the rain-water control, the leachate of *V. negundo* significantly retarded the growth of *Digitaria decumbens* but stimulated the growth of *Andropogon nodosus*. The growth of *D. decumbens* in pots under greenhouse conditions was significantly retarded by watering with a 1% aqueous extract of *V. negundo*, but the growth of *Andropogon nodosus* and *M. pudica* was stimulated. The aqueous extract was phytotoxic to lettuce and ryegrass seeds. The aqueous effluents from a polyamide column chromatograph were bioassayed; some fractions inhibited the growth of lettuce and rice seedling radicles, whereas other fractions stimulated growth. The responsible substances, isolated and identified, included several phenolic acids and ten flavonoids, including 3'-hydroxyvitexin and its derivative (Figure 2) (Chou and Yao, 1983). These metabolites have potential usefulness as herbicides.

In connection with a chemosystematic investigation of *Agastache pallidiflora*, Chou et al. (1979) identified 6 flavonoids, namely kaempferol, quercetin 3-rhamnoside, kaempferol 3-galatoside, diosmetin 7-glucoside, and acacetin 7-glucoside. The alycone moiety of flavonoids may exhibit allelopathic nature, yet the biological activity has not been fully confirmed.

Alkaloids

The mature leaves of *Leucaena* possess about 5% dry weight of mimosine (Figure 1), the amount varying with varieties. The seed germination and radicle growth of lettuce, rice, and rye grass were significantly inhibited by aqueous mimosine at a concentration of 20 ppm, while that of the forest species mentioned was suppressed by the mimosine solution at 50 ppm or above. However, the growth of *Miscanthus floridulus* was not suppressed by the mimosine solution at 200 ppm (Chou and Kuo, 1986). Of eighty-four *M. pudica* seedlings tested, only two seedlings survived, showing that mimosine can be of practical use in the control of field weeds.

Recently, Chou and Leu (1992) reported another plant, *Delonix regia*, which allelopathically excludes understory species. The aqueous extracts of the leaves, flowers, and twigs of *D. regia* revealed significant phytotoxicity (over 70%) against tested species such as *Isachne nipponensis* and *Centella asiatica*. The responsible allelopathic substances are 3,4- dihydroxybenzaldehyde and the acids: 4-hydroxybenzoic; chlorogenic; gallic; 3,4-dihydroxybenzoic; 3,4-dihydroxycinnamic; 3,5-dinitrobenzoic (Table 1, Figure 1); and L-azetidine-2-carboxylic (Figure 3). In addition, some unidentified flavonoids are present in the plant.

Furthermore, regarding the allelopathic compounds isolated from *Coffea arabica*, there are 7 phenolic compounds and 4 alkaloids, namely caffeine, theobromine, theophylline, and paraxanthine (Figure 3). At the concentration of 100 ppm in aqueous solution, the alkaloids exhibited significant phytotoxicity of test plants (Chou and Waller, 1980). Waller et al. (1989) further studied the action model of these alkaloids and interesting findings were associated with biosysthesis of proten and nucleic acids.

Allelopathy in Pasture-forest Intercropping Systems

Taiwan is an island, two thirds of which is mountainous, and its forests are extremely important for water conservation. The limited amount of agricultural land forces farming activities into the hills and to higher elevations. A forest-pasture intercropping system is thought to be a way to solve the probloem and to increase livestock production. Recently we have conducted several experiments in the forest area of Hoshe Experiment Station of National Taiwan University, located at an elevation of about 1200 meters (Chou et al., 1987). A one-hectare area was deforested. The leaf litter of the conifer tree *Cunninghamia lanceolata* was removed from part, and the rest was left unchanged, as the control. The half of the test plot adjacent to the control plot was planted with kikuyu grass (*Pennisetum clandestinum*) and the other half left open. The experiment was designed to determine the reciprocal interaction of fir litter and kikuyu grass, and to evaluate the allelopathic influence of the two plants on weed growth. The biomass of kikuyu grass invading the cleaned plot was significantly higher than that invading the control plot (Chou et al., 1987). In addition, the number of weeds that grew in the plot planted with kikuyu grass was lower than that in the control plot, indicating that the kikuyu grass may compete with and suppress weeds. The seedlings of fir regenerating in the deforested area grew well and seemed not to be affected by the neighboring newly planted kikuyu grass. The growth of kikuyu grass, however, was inhibited by the fir litter left on the unchanged plot in the first three months after deforestation. Bioassay of aqueous extracts showed that the fir litter extract exhibited higher phytotoxicity than did the kikuyu grass. Nevertheless, four months after deforestation the growth of kikuyu grass in the field was luxuriant, indicating that the phytotoxicity of fir litter disappeared (Chou et al., 1987).

In another experiment (Chou et al., 1989), a split plot design of eight treatments was set up after deforestation of Chinese fir (*Cunninghamia lanceolata*): open ground without planting (control), planted with kikuyu grass, planted with kikuyu grass and *Alnus formosana*, planted with kikuyu grass and *Zelkova formosana*, planted with kikuyu grass and *Cinnamomum camphora*, planted with *A. formosana*, planted with *Z. formosana*, and planted with *C. camphora*. Field measurements showed that weeds grew luxuriantly six months after treatment in plots which had not been planted with kikuyu grass. The growth of weeds was significantly retarded, but that of woody plants was not affected when the plots were planted with kikuyu grass. Compared to the tap-water control, the aqueous leachate of kikuyu grass stimulated the seedling growth of *C. camphora* and *A. formosana*, but the extract stimulated the growth of *C. camphora* and inhibited that of *A. formosana*. The aqueous extracts of three hardwood plants had varied inhibition on the root initiation of kikuyu grass. The aforementioned extracts and leachates were bioassayed against seed germination and radicle growth of four test plants, including *Miscanthus floridulus*. The extract of *Z. formosana* revealed the highest phytotoxic effect on the test species while that of kikuyu grass showed the least effect. The phytotoxic phenolics (Table1, Figure 1) were identified by means of chromatography. The quantity of phytotoxins present was highest in the extract of *Z. formosana* and was lowest in that of kikuyu grass. The degree of phytotoxicity and quantity of phytotoxins was in good correlation, indicating that a selective allelopathic effect was involved (Chou et al., 1989).

Conclusions

Allelopathic chemicals could only temporarily suppress plant growth and regulate species diversity without making species extinction because naturally occuring compounds are rapidly degradated into nontoxic compound and reveal less residual effect. However, the synthetic agrochemicals often exhibit greater toxicity and are difficult to be decomposed, leading to a longer residual effect on living organisms, causing environmental pollution. In sustainable development of agriculture, we have to be aware of the importance of biodiversity and balance of ecosystems, otherwise, the benefit of our economic success and agricultural production through advanced scientific technology would be overthrown by feedback of environmental deterioration.

Acknowledgement: The research was supported in part by Academia Sinica, Taipei, the National Science Council, and the Joint Commission of Rural Reconstruction, the Council of Agriculture of the Republic of China. The author is grateful to his former collaborators, assistants and graduate students for their collaboration and assistance, and to Mr. David L. Bergart for his excellent editing this manuscript.

References

Chang, T. T. 1992. Maintenance of biological diversity in sustainable agricultural productivity - an imperative. pp. 13-17. *in* The Impact of Biological Research on Agricultural Productivity. Proc. of the SABRAO International Symposium. The Society of the Advancement of Breeding Researches in Asia and Oceania.

Chou, C. H. 1989. The role of allelopathy in phytochemical ecology. *In* Phytochemical Ecology: Allelochemicals, Mycotoxins, and Insect Pheromones and Allomones. Chou, C. H. and Waller, G. R. (eds.). Institute of Botany, Academia Sinica, Monograph 9, Academia Sinica, Taipei. pp. 19-38.

Chou, C. H. 1992. Allelopathy in relation to agricultural productivity in Taiwan: Problems and Prospects. In Rizvi, S. J. H. and Rizvi, V. (eds.), Allelopathy: basic and applied aspects. Chapman and Hall, London. pp. 179-204.

Chou, C. H. 1993. The role of allelopathy in the diversity of plant communities in Taiwan. Bot. Bull. Academia Sinica 34: 211-221.

Chou, C. H., Chang, S. J., Cheng, C. M., Wang, Y. C., Hsu, F. H., and Den, W. H. 1989. The selective allelopathic interaction of a pasture-forest intercropping in Taiwan II. Interaction between kikuyu grass and three hardwood plants. Plant and Soil 116: 207-215.

Chou, C. H. and Chen, C. S. Andrew. 1976. Leaching metabolites in the vegetation of northern Taiwan II. Allelopathic potential of some vegetations in northern Taiwan. Memorial Volume to President Chiang Kai-Shek, Academia Sinica, Taipei, Taiwan. pp. 365-383.

Chou, C. H. and Chung, Y. T. 1974. The allelopathic potential of *Miscanthus floridulus*. Bot. Bull. Academia Sinica 15:14-27.

Chou, C. H. and Hou, M. H. 1981. Allelopathic researches of subtropical vegetations in Taiwan. Evaluation of allelopathic potential of bamboo vegetation. Proc. Nat. Sci. Coun. (ROC) Part B: 5(3): 284-292.

Chou, C. H., Hwang, S. Y., Peng, C. I., Wang, Y. C., Hsu, F. H., Chung, N. J. 1987. The selective allelopathic interaction of a pasture-forest intercropping in Taiwan. Plant and Soil 98:31-41.

Chou, C. H. and Kuo, Y. L. 1987. Allelopathic research of subtropical vegetation III. Allelopathic exclusion of understory by *Leucaena leucocephala*. J. Chem. Ecol. 12: 1431-1448.

Chou, C. H. and Lee, Y. F. 1991. Allelopathic dominance of Miscanthus transmorrisonensis in an alpine grassland community in Taiwan. J. Chem. Ecol. 17:2267-2281.

Chou, C. H. and Leu, L. L. 1992. Allelopathic substances and interactions in *Delonix regia* Raf. J. Chem. Ecol. 18:2285-2303.

Chou, C. H., Ulebelen, A. and Mabry, T. J. 1979. Chemistry of *Agastache* Part I. Flavonoids of *Agastache pallidiflora*. Rev. Latinoamer. Quim. 10: 136.

Chou, C. H. and Waller, G. R. 1980. Possible allelopathic constituents of *Coffea arabica*. J. Chem. Evol. 6:643-654.

Chou, C. H. and Waller, G. R. 1989. (eds.) Phytochemical Ecology: Allelochemicals, Mycotoxins, and Insect Pheromones and Allomones. Institute of Botany, Academia Sinica Monograph Series No.9, Academia Sinica, Taipei.

Chou, C. H. and Yang, C. M. 1982. Allelopathic research of subtropical vegetation in Taiwan II. Comparative exclusion of understory by *Phyllostachys edulis* and *Cryptomeria joponica*. J. Chem. Ecol. 8: 1489-1507.

Chou, C. H. and Yao, C. 1983. Phytochemical adaptation of coastal vegetation in Taiwan I. Isolation , identification and biological activities of compounds in *Vitex negundo*. Bot. Bull. Academia Sinica 24: 155-168.

Chou, C. H. and Young, C. C. 1975. Phytotoxic substances in twelve subtropical grasses. J. Chem. Ecol. 1: 183-193.

Fraenkel, G. S. 1959. The raison d'etre of secondary plant substances. Science 129:1466-1470.

Ehrlich, P. R. and Raven, P. M. 1965. Butterfilies and plants: a study in coevolution: Evolution (Lancaster) 18:586-

Francis, C. A. and Sahs, W. W. 1986. Research for sustainable agriculture by U.S. universities. Paper presented at IFOAM 6th International Conference, Santa Cruz, California. August 18-21, 1986.

Gajic D. and Nikocevic, G. 1973. Chemical allelopathic effect of *Agrostemma githago* upon wheat. Fragm. Herb. Jugoslavia 18:1-5.

Gliessman, S. R. 1986. Plant interactions in multiple cropping systems. *in* Multiple Cropping Systems. C. A. Francis (ed.). Mac-Millan Publ. Crop. New York, Chapter 5.

Harborne, J. 1977. Introduction to Biochemical Ecology. Academic Press, London and New York.

Koeppe, D. E., Southwick, L. M. and Bittell, J. E. 1976. The relationship of tissue chlorogenic and concentration and leaching of phenolic from sunflowers grown under varying phosphate nutrient condition, Can. J. Bot. 54: 593-599.

Muller, C. H. 1966. The role of chemical inhibition (allelopathy) in vegetational composition. Bull. Torrey Bot. Club 93: 332-351.

Muller, C. H. and Chou, C. H. 1972. Phytotoxins: an ecological phase of phytochemistry. pp. 201-212. *in* Phytochemical Ecology. J. Harborne (ed.). Academia Press, London and New York.

Patrick, Z. A. 1971. Phytotoxic substances associated with the decomposition in soil of plant residues. Soil Sci. 111:13-18.

Putnam, A. R. and Duck, W. D. 1974. Biochemical suppression of weeds: evidence for allelopathy in accessions of cucumber. Science 185:370-372.

Rice, E. L. 1984. Allelopathy. Academic Press, New York, London, 422pp.

Rizvi, J. H. and Rizvi, V. (eds.). 1992. Allelopathy: basic and applied aspects. Chapman and Hall, London.

Waller, G. R. 1987. (ed.). Allelochemicals: Role in agriculture and Forestry. ACS Symposium series 330. Washington, D.C.

Waller, G. R. and Nowacki, E. K. 1975. Alkaloid Biology and Metabolism in Plants. Plenum Press, N. Y. and London.

Whittaker, R. H. and Feeny, P. P. 1971. Allelochemics: Chemical interactions between species. Science 171:757-770.

Wu, M. M., Liu, C. L. and Chao, C. C. 1976a. Identification and purification of the phytotoxin produced by *Fusarium oxysporum* Schl. in relation to yield decline of ratoon cane. J. Chinese Agr. Chem. Soc. 14(3,4): 160-165.

Wu, M. H., Liu, C. L., Chao, C. C., Shieh, S. W. and Lin, M. S. 1976b. Microbiological biochemical studies on the cause of low yielding in the second crop of rice. Chinese Agr. Chem. Soc. 96:16-37. (in Chinese).

Yang, R. Z. and Tang, C. S. 1988. Plants used for pest control in China: A literature review. Eco. Bot. 42:376-406.

Table 1. Presence (+) of phytotoxic phenolic compounds as naturally occurring herbicides in grasses and woody plants in Taiwan

Compounds	Grasses					Woody plants					
	Dd(1)	Mf	Mt	Pc	Pe	Af	Ca	Cl	Dr	Ll	Zf
Caffeic acid			+				+			+	
Chlorogenic acid							+		+		
Cinnamic acid	+			+		+					+
o-Coumaric acid											+
m-Coumaric acid				+				+			
p-Coumaric acid	+	+		+	+		+			+	
3,4-Dihydroxy-benzaldehyde									+		
3,4-Dihydroxybenzoic acid									+		
3,4-Dihydroxycinnamic acid									+		
3,5-Dinitrobenzoic acid									+		
Ferulic acid	+	+	+	+	+			+		+	+
Gallic acid			+	+				+	+	+	
p-Hydroxybenzoic acid	+	+	+	+	+		+	+	+	+	
p-Hydroxyphenylacetic acid										+	
o-Hydroxyphenylacetic acid	+	+	+		+	+					
Phloridzin			+								
Protocatechuic acid				+				+		+	+
α-Resorcylic acid						+					
β-Resorcylic acid											
γ-Resorcylic acid						+					+
Scopoletin							+				
Syringic acid	+	+		+	+		+	+			
Vanillic acid	+	+	+	+	+	+	+	+		+	+
4-Hydroxycoumarin			+								

(1) Abbreviations of each plant name are: Dd: *Digitaria decumbens*
Mf: *Miscanthus floridulus*, Mt: *M. transmorrisonensis*
Pc: *Pennisetum clandestinum*, Pe: *Phyllostachys edulis*
Af: *Alnus formosana*, Ca: *Coffea arabica*, Cl: *Cunninghamia lanceolata,* Dr: *Delonix regia*
Ll: *Leucaena leucocephala*, Zf: *Zelkova formosana.*

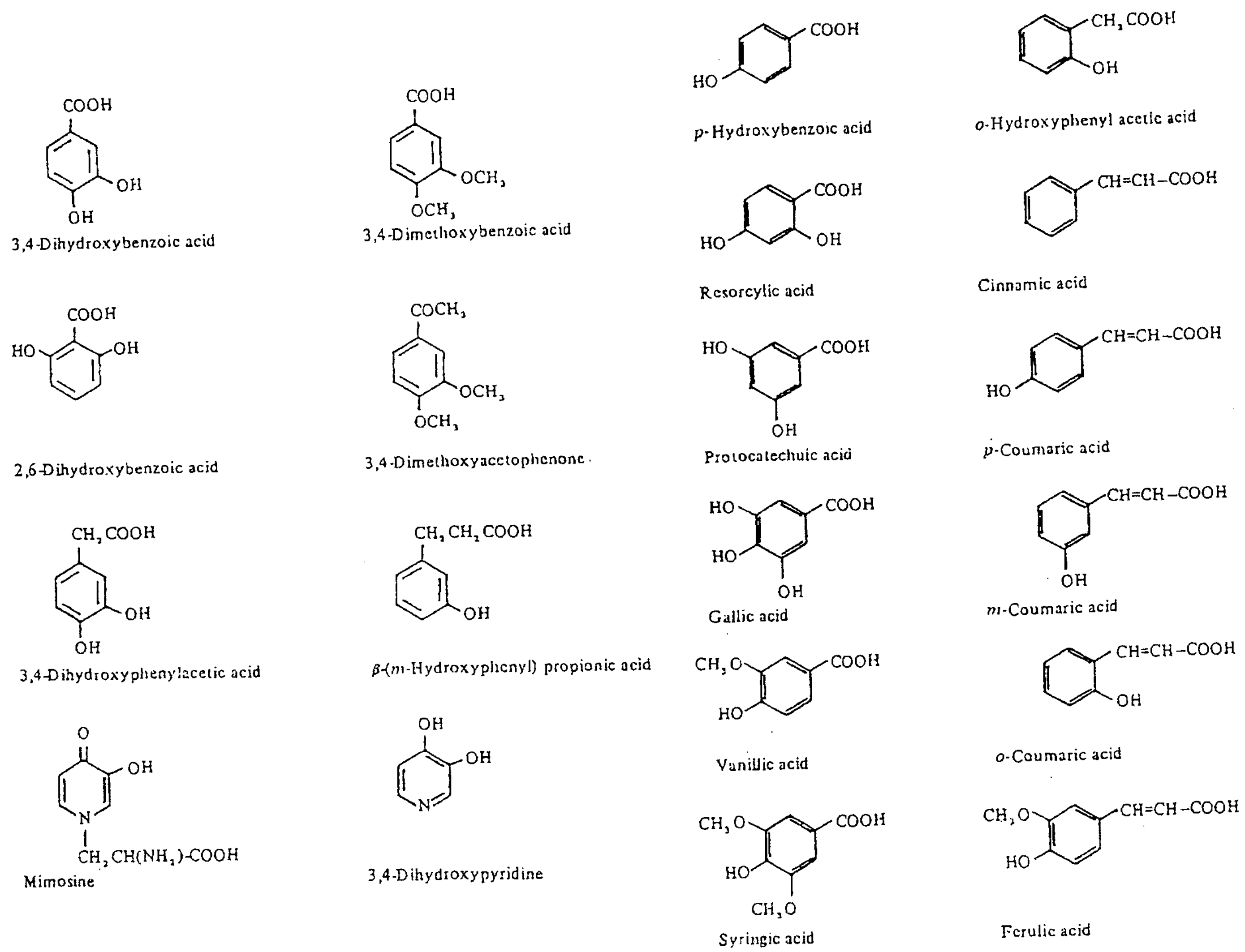
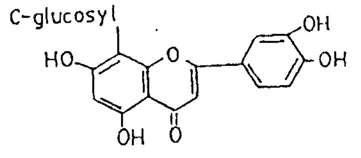
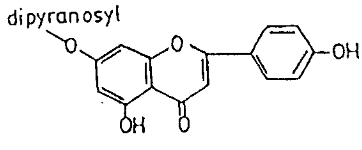


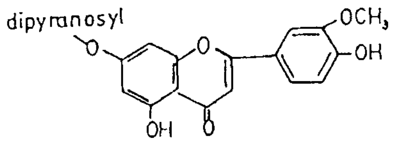
Figure 1. Chemical structure of potential allelopathic phenolics isolated from plant parts mentioned in the text.



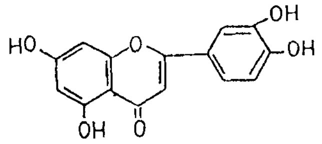
I



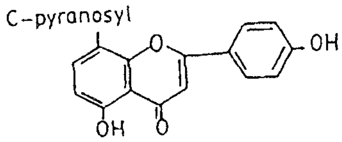
II



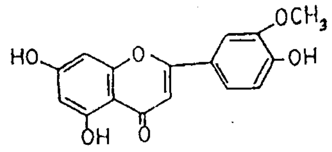
III



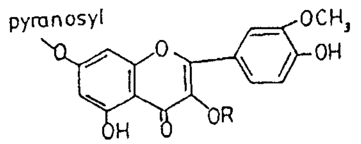
IV



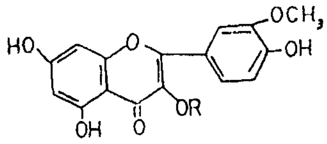
V



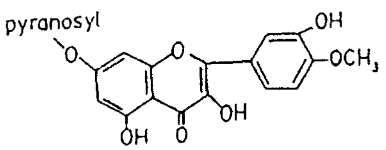
VI



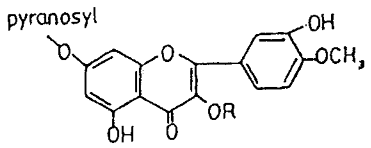
VII



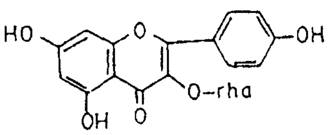
VIII



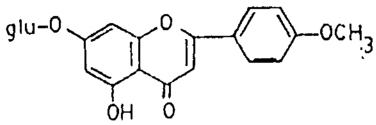
IX



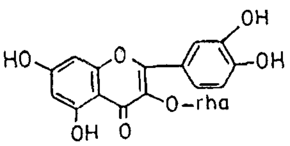
X



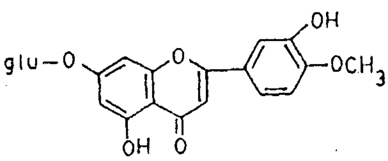
XI



XII



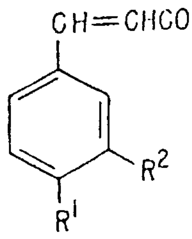
XIII



XIV

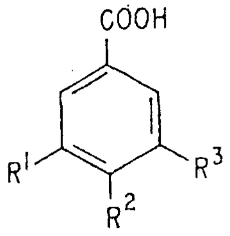
Figure 2. Chemical structure of potential allelopathic flavonoids (I-X) isolated from *Vitex negunda* and flavonoids (X I - X IV) isolated from *Agastache pallidiflora*. Compounds X I to X IV are:

X I = Kaempferol 3-rhamnoside,
X II = acacetin 7-glucoside,
X III = qucertin 3-rhamnoside
X IV = diosmetin 7-glucoside



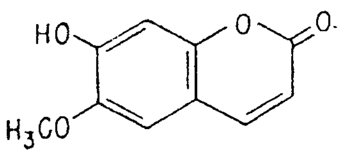
$R^1 = R^2 = OH$ Caffeic acid

$R^1 = OH$, $R^2 = H$ *p*-Coumaric acid

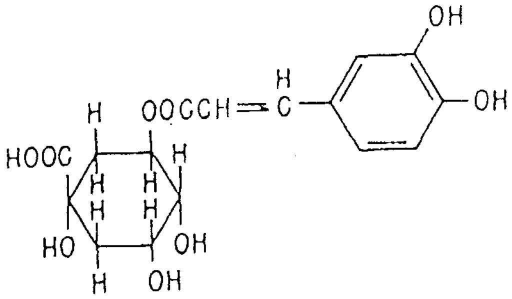


$R^1 = R^3 = H$, $R^2 = OH$ *p*-Hydroxybenzoic acid

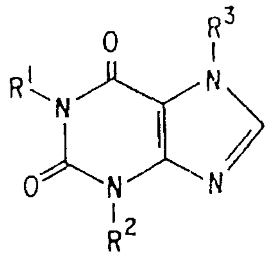
$R^1 = H$, $R^2 = OH$, $R^3 = OCH_3$ Vanillic acid



Scopoletin



Chlorogenic acid

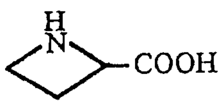


$R^1 = R^2 = R^3 = CH_3$ Caffeine

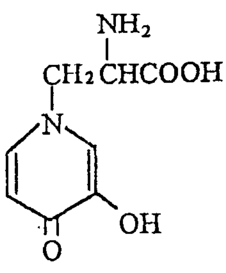
$R^1 = R^2 = CH_3$, $R^3 = H$ Theophylline

$R^1 = R^3 = CH_3$, $R^2 = H$ Paraxanthine

$R^2 = R^3 = CH_3$, $R^1 = H$ Theobromine



2-Azetidine carboxylic acid



Mimosine

Figure 3. Chemical structure of potential allelopathic phenolics and alkaloids from plant parts mentioned in the text.

HERBICIDE SAFENERS: RECENT ADVANCES AND BIOCHEMICAL ASPECTS OF THEIR MODE OF ACTION

Klaus Kreuz+, Slobodan Farago*, Shiaki Murakami^, Hans C. Steinruecken*
+Ciba Crop Protection, R&D Weed Control, Plant Biochemistry, *International Research Laboratories, Ciba Geigy Japan, 10-66, Miyuki-cho, Takarazuka 665, Japan; ^Agricultural Division Ciba Geigy Japan, 4-1, Hamamatsu-cho, 2-chome Minoto-ku, Tokyo 105, Japan

Herbicide safeners are a group of chemically diverse compounds with the ability to improve the crop selectivity of certain herbicides. Several agrochemical companies have commercially developed safeners for thiocarbamate, chloroacetanillide, and aryloxy-phenoxypropionate herbicides in major monocotyledonous crops including maize, small grain cereals, rice, and grain sorghum. Safeners are employed to extend the use of available herbicides on additional crops and to exploit new herbicides with marginal crop selectivity. There is considerable evidence that safeners act by accelerating herbicide metabolism and detoxification in crop plants. Metabolic reactions that are enhanced include oxidation (hydroxylation, oxidative dealkylation) and conjugation to endogenous moieties such as glucose and glutathione. A number of enzymes involved in these metabolic pathways, such as glutathione S-transferase isozymes and various forms of cytochrome P450-dependent monooxygenase activities, have been shown to be induced by safeners. Safeners have also been reported to increase the biosynthesis and accumulation of glutathione, and to enhance the process of compartmentation of herbicide conjugates. The botanical specificity of safener protection has been investigated in the light of the recently developed aryloxyphenoxypropionate herbicide and safener combination, clodinafopropargyl and cloquintocet-mexyl (Topik®). The herbicide exhibits different metabolic routes in wheat and in target weeds, and only crop specific herbicide metabolism is enhanced by the safener.
®- is registered trademark of Ciba-Geigy AG
key words: Safener,, glutathione S-transferase, glutathione, cyt P-450monooxygenase, Topik

INTRODUCTION

Weed management in modern agriculture requires efficient weed control technologies that are safe to the crop. The search for environmentally compatible herbicides with high biological activity and crop selectivity is a challenge for agrochemical research. Insufficient crop tolerance is one of the major constraints in the development of new herbicides and in the use of existing herbicides in particular crops or under unfavourable environmental conditions. Based on the available knowledge of the mechanisms of herbicide selectivity, the chemical optimization of lead structures for crop selectivity will in the foreseeable future depend more on broad-based synthesis and testing of herbicidal molecules rather than on ~rational design~ (Brown et al., 1991). Recent efforts are thus aimed at protecting crops from herbicidal injury by means of selection or genetic engineering of herbicide tolerant crop cultivars (Hinchee et al., 1993) Another approach is to improve crop tolerance to new and existing herbicides by herbicide safeners.

THE SAFENER CONCEPT

Herbicide safeners are a group of chemically diverse compounds with the unique ability to protect crop plants from injury by certain herbicides without impairing weed control efficacy. The safener concept has been established by the pioneering work of O. L. Hoffmann (Stephenson & Yaacoby, 1991). After the initial discoveries of naphthalic anhydride (naphthalene-1,8-carboxylic anhydride) and dichlormid (N,N-diallyl-2,2-dichloroacetamide) as herbicide safeners, a number of other safeners have been developed for all major monocotyledonous crop species including maize, small grain cereals, rice and grain sorghum. In most crop-weed associations, selective improvement of crop tolerance can be achieved with safeners applied as mixed formulations with the herbicide; however, seed-treatment with safeners is also currently used, mainly in grain sorghum, to protect only the crop and not botanically closely related weeds. Safeners have been exploited in two ways: to improve tolerance of newly developed herbicide with limited selectivity on target crops, and to extend the use of available herbicides on additional crops.

In the past, the search for safeners has been most successful for pre-plant soil incorporated and pre-emergence herbicides of the thiocarbamate and chloroacetanilide classes in maize, and for chloroacetanilides in sorghum and wet-sown rice. More recently, safeners have also been developed for post-emergence grass weed control in cereals in combination with aryloxyphenoxypropionate herbicides. Protection by various safeners has also been reported for members of several other herbicide classes such as the sulfonylureas, imidazolinones, cyclohexanediones, and isoxazolidinones.

MECHANISMS OF ACTION OF HERBICIDE SAFENERS

Several hypotheses have been advanced for the mechanism(s) of the protective action of herbicide safeners. It has been suggested that safeners may reduce herbicide uptake or translocation to sensitive site(s) within the plant, or increase the rate of herbicide metabolism and detoxification. Alternativly, safeners may prevent binding of the herbicide to the cellular target site, or antagonize herbicidal effects at the physiological level. Finally, a combination of several of these factors may be encountered. Understanding of herbicide-safener interactions is hampered by a general lack of exact knowledge of the herbicidal mechanisms ultimately leading to plant injury. However, there is a large body of evidence that the hitherto commercialized safeners protect crop plants by enhancing herbicide metabolism and detoxification.

a.) Enhancement of herbicide metabolism

Differences in herbicide metabolism and detoxification between tolerant and susceptible plant species have long been recognized as one important mechanism contributing to the selective action of many herbicides (Owen, 1987). Biotransformations of herbicides in plants generally include oxidation, hydrolysis, reduction (rarely), and conjugation to e.g. glutathione, glucose, or amino acids. To date, two different metabolic pathways have been related to the mode of action of herbicide safeners. The first represents the conjugation of chloroacetanilide and sulfoxidized thiocarbamate herbicides with glutathione; the second includes hydroxylation and subsequent glucose conjugation. The latter pathway appears to be important predominantly in safener protection to aryloxyphenoxypropionate, sulfonylurea, and imidazolinone herbicides.

b) Glutathione conjugation and glutathione S-transferases

Conjugation of herbicides *via* the thiol function of reduced glutathione (γ-glutamylcysteinylglycine) is well established as one of the major detoxification and selectivity factors in plants (Lamoureux et al., 1991). Though glutathione conjugations can proceed nonenzymatically at appreciable rates with some substrates, the reactions are usually accelerated through catalysis by glutathione S-transferase enzymes (EC 2.5.1.18). The rate of glutathione conjugation of herbicides in plants may be regulated, in principle, by both glutathione S-transferase level and activity as well as by glutathione availability.

Chloroacetanilide herbicides are initially metabolized in plants through glutathione conjugation by nucleophilic displacement of chlorine from the chloroacetyl side chain, without the need for a preceding metabolic step to increase electrophilicity. Fuerst & Gronwald (1986) have shown that protection of sorghum from metolachlor injury by oxabetrinil and other safeners is closely correlated with their ability to accelerate metolachlor metabolism in shoot tissue. Maize exhibits reduced tolerance to metolachlor and other chloroacetanilide herbicides under certain adverse growing conditions such as high soil moisture and low soil temperature before seedling emergence. Effects of soil temperature have been related in part to a slower rate of herbicide metabolism, as well as to greater herbicide exposure due to slower seedling emergence (Viger et al., 1991). The safener benoxacor protects maize from metolachlor injury under a wide range of environmental conditions (Peek a al., 1988). The predominant site of uptake of pre-emergence applied chloroacetanilides is the coleoptile of germinating grass species, while the primary anatomical sites affected are the enclosed developing leaves and apical and intercalary meristems (LeBaron et al., 1988). After shoot application of metolachlor a comparatively small proportion of the herbicide moved into the enclosed developing leaves, and most of the absorbed herbicide was retained in the coleoptile and was metabolized there *via* glutathione conjugation (Kreuz et al. 1989). The developing leaves, however, were found to be relatively slow to metabolize metolachlor as compared to the coleoptile. They also exhibited the lowest glutathione S-transferase activity of all seedling tissues examined. Benoxacor significantly reduced the concentration of unmetabolized metolachlor mainly in the developing leaves, but also in the coleoptile and mesocotyl, as a consequence of enhanced metabolism. Activity of glutathione S-transferase accepting metolachlor as substrate was increased fivefold in seedling shoots upon benoxacor treatment (Kreuz et al., 1989; Viger et al., 1991). Similar results were reported from studies with metazachlor and the safener BAS 145138 (l-dichloroacetylhexahydro-3,3,8α-trimethylpyrrolo[1,2-α]-pyrimidin-6-(2H)-one) in maize (Fuerst & Lamoureux, 1992).

In maize, sorghum and rice, herbicide safeners increase the extractable glutathione S-transferase activities as evaluated with the model substrate l-chloro-2,4-dinitrobenzene, chloroacetanilide herbicides, and EPTC-sulfoxide (maize only). Constitutive and safener-induced glutathione S-transferases from sorghum and maize have been distinguished based on chromatographic elution characteristics and differential activities towards various substrates (Dean et al., 1990; Fuerst a al., 1993). Maize contains at least two major constitutive glutathione S-transferase isozymes accepting metolachlor as substrate and whose activities were enhanced by treatment of seedlings with benoxacor. A third such isozyme was found to be absent constitutively and highly induced by benoxacor (Fuerst a al., 1993).Complementary DNAs for two maize glutathione S-transferases have been cloned and the deduced amino acid sequences were shown to possess some similarity to each other as well as to animal glutathione S-transferases (reviewed by Timmerman, 1989). Safener induction of glutathione S-transferase activity is associated with a net accumulation of enzyme protein and requires *de novo* protein synthesis. The steady-state levels of messenger RNA coding for a particular isozyme subunit were increased in maize treated with dichlormid or flurazole (benzyl 2-chloro-4-trifluoromethylthiazole-5-carboxylate), which suggests that regulation of enzyme synthesis by safeners is exerted at the level of gene transcription.

c.) Regulation of glutathione levels and biosynthesis

Safeners have repeatedly been shown to increase the tissue concentration of reduced glutathione in plants, yet the significance of elevated glutathione levels for safener action is still uncertain. A weak correlation has been found between the increase in glutathione content of sorghum shoots and the degree of protection from metolachlor injury conferred by a particular safener (Gronwald a al., 1987). On the other hand, decreased glutathione contents of maize shoots due to treatment with buthionine sulfoximine, an inhibitor of γ-glutamylcysteine synthetase, are correlated with increased metolachlor susceptibility (Farago et al., 1993). In roots of maize seedlings, dichlormid and benoxacor increased the contents of free cysteine and glutathione and enhanced the biosynthesis of these thiols from inorganic sulfate (Farago & Brunold, 1990,1994). This was attributable to an increase in the extractable activities of adenosine 5'-phosphosulfate sulfotransferase and ATP-sulfurylase (EC 2.7.7.4) two key regulatory enzymes of assimilatory sulfate reduction and γ-glutamylcysteinesynthetase. Glutathione reductase activity (EC 1.6.4.2) has also been reported to be enhanced in the shoots of safener-treated maize seedlings (Komives et al., 1985).

d.) Oxidative metabolism and cytochrome P450 monooxygenases

Oxidation and subsequent glucose conjugation constitutes a very important pathway responsible for herbicide selectivity that has recently also been associated with safener action. Oxidation appears not always to afford complete herbicide detoxification, but is frequently a necessary and rate-limiting step for subsequent glucose conjugation. Safeners have been shown to stimulate oxidative metabolism of herbicides belonging to the groups of sulfonylureas, imidazolinones and aryloxyphenoxypropionates in plants *in vivo* (Hatzios, 1991).

There is accumulating evidence that cytochrome P450-dependent monooxygenases (EC 1.14.14.1) play a pivotal role in the oxidation of many herbicides in plants. The cytochromes P450 found in plants are, like the well-characterized ones in the endoplasmic reticulum from mammalian liver, membrane-bound haemoproteins of approximately 55 kDalton molecular mass (Donaldson & Luster, 1991). They require molecular oxygen for catalytic activity, NADPH, and a second protein component, the flavoprotein NADPH-cytochrome P450 reductase. Reactions mediated by plant cytochrome P450-monooxygenases on herbicide substrates include aryl and alkyl hydroxylations and oxidative N- and O-demethylations. Conclusive evidence for the involvement of cytochrome P450-monooxygenases in plant herbicide metabolism has been obtained for 2,4-D, diclofop, bentazone, flumetsulam (N-(2,6-difluorophenyl)-5-methyl-1,2,4-triazolo[1,5-α]pyrimidine-2-sulfonamide), metolachlor and members of the phenylurea and sulfonylurea herbicide classes (Moreland et al, 1993 and references cited therein; Frear et al, 1993). The criteria that have been employed to demonstrate cytochrome P450 monooxygenase catalysis in those reactions include spectral evidence, photoreversible inhibition of these reactions by carbon monoxide, requirement for molecular oxygen and NADPH, sensitivity to known cytochrome P450 inhibitors and involvement of NADPH-cytochrome P450 reductase activity. Despite considerable experimental difficulties, e.g. low constitutive enzyme activity levels, apparent instability of the enzymes and presence of endogenous inhibitors in crude microsomal preparations, much effort has been devoted in recent years to elucidate the putative multiplicity of cytochrome P450 isoforms and the regulation implicated in safener action. These studies have revealed that microsomes isolated from plants treated with herbicide safeners or other xenobiotics, such as ethanol and phenobarbital, contain elevated cytochrome P450 monooxygenase activities towards particular substrates (Fonne-Pfister et al., 1990; Frear et al., 1991; Moreland et al., 1993). Studies in grain sorghum have shown that microsomal cytochrome P450-linked metabolism of bentazone hydroxylation), diazinon (desulfuration and oxidative dearylation) and lauric acid (in-chainhydroxylation) is stimulated to varying degrees by a number of safeners applied to the seed prior to planting (Moreland et al., 1993). Cytochrome P450-mediated oxidation of several herbicides and its induction by naphthalic anhydride, ethanol, or phenobarbital has been demonstrated in wheat (Frear et al., 1991). In this system, increases in monooxygenase activities as determined with diclofop, chlorsulfuron and triasulfuron as substrates ranged from five- to twentyfold, depending on the particular substrate and on the inducer employed. Interestingly, strong evidence has been obtained that in wheat diclofop aryl hydroxylase is identical with lauric acid (ω-1) hydroxylase which, for the first time links a herbicide-metabolizing monooxygenase activity to a particular cytochrome P450 isoform that participates in a defined physiological reaction (Zimmerlin & Durst, 1992). Both enzyme activities exhibited similar induction patterns with naphthalic anhydride and phenobarbital.

e.) Glucose conjugation

Metabolism of herbicides to derivatives containing free hydroxy groups is generally followed by extensive carbohydrate conjugation, with O-β-D-glucosides representing the most common group of these conjugates (Lamoureux et al., 1991). Glucose conjugation seems in some cases necessary to complete herbicide detoxification; since free hydroxylated metabolites do not commonly accumulate to significant levels in plants, glucosylation appears *prima facie* not an important site for safener action. During metabolism of chlorimuron-ethyl in maize, however, hydroxylation at the 5-position of the pyrimidine ring yielded the major metabolite, 5-hydroxychlorimuron-ethyl (Lamoureux & Rusness. 1992). Chlorimuron-ethyl causes injury to maize that can be alleviated by BAS 145138. This safener increased the capacity for 5-pyrimidyl-O-glucoside formation from chlorimuron-ethyl, and feeding experiments with 5-hydroxychlorimuron-ethyl revealed that the *in vivo* rate of glucosylation was indeed accelerated. The glucose conjugate was less inhibitory *in vitro* towards the target enzyme, acetolactate synthase, as compared to the free hydroxychlorimuron-ethyl. Interestingly, the safener BAS 145138 increased, in addition to glucose conjugation, the capacity for pyrimidine-ring hydroxylation as well as glutathione conjugation of chlorimuron-ethyl in maize. Evidence for a safener-induced increase in the rate of glycosylation has also been obtained with a hydroxylated aryloxyphenoxypropionate herbicide in wheat (Kreuz et al., 1991).

f.) Secondary metabolism of herbicide conjugates and compartmentation processes

Glutathione conjugates of herbicides in plants usually undergo extensive processing to e.g. cysteine or thiolactic acid derivatives and conjugates thereof with malonate, to name but a few (Lamoureux a al., 1991). Simple glucose conjugates are frequently subject to secondary conjugations to carbohydrate or malonyl residues. Terminal products may be stored as soluble metabolites, presumably in the vacuole, or deposited as "bound residues" into cell wall components. Formation of soluble secondary metabolites and bound residues from the initial glutathione conjugates of propachlor and metolachlor in maize was only marginally influenced by the safener BAS 145138 and therefore appeared to be of minor significance for safener action (Khalifa & Lamoureux, 1990).

Circumstantial evidence indicates a reduced mobility in the plant of herbicide conjugates as compared to the parent herbicides (see e.g. Fuerst & Lamoureux, 1992). This is conceivably due to the lower membrane permeability of hydrophilic conjugates, but specific compartmentation processes have also been inferred. The commonly observed addition of a malonyl residue to initially formed glucose conjugates or glutathione-derived cysteine and thiolactic acid conjugates has been proposed to be a mechanism to facilitate transport into the vacuole (Lamoureux a al., 1991). However, vacuolar localization of herbicide conjugates has rarely been demonstrated, and transport processes have apparently not been investigated as yet. Only recently, active transport of the glutathione conjugates of metolachlor and other xenobiotics into the plant vacuole has been discovered and shown to be mediated by an ATP-dependent carrier in the tonoplast membrane (Martinoia et al.,1993). This vacuolar carrier showed a striking resemblance to the glutathione S-conjugate export pump in the canalicular membrane of mammalian liver. It is not yet known whether such transport processes into plant vacuoles are influenced by herbicide safeners.

g.) Specificity of safener action

Safeners used as a tank-mixture or prepackaged formulation with the herbicide act specifically with respect to the plant species that are protected from herbicidal injury. Fenchlorazole-ethyl, a compound developed for use in conjunction with the aryloxyphenoxypropionate herbicide, fenoxaprop-ethyl, has been reported to act as both a safener on wheat and as a synergist of herbicidal action on *Digitaria ischaemum* (Yaacoby et al., 1991). In both plant species, fenchlorazole-ethyl stimulated deesterification of fenoxaprop-ethyl to the herbicidally active free acid. Further metabolism and detoxification of the herbicide, however, was only enhanced in wheat but not in *D. ischaemum*. More recently, specific safener action of cloquintocet-mexyl (5-chloro-8-quinolinoxyacetic acid-l-methylhexyl ester) for the herbicide clodinafop-propargyl (2-propynyl-R-2-[4-(5-chloro-3-fluoro-2-pyridinyloxy)-phenoxy]propionate) on wheat (Amrein et al, 1989) could be explained on the basis of the qualitatively different metabolic pathways of the herbicide in wheat and in susceptible target weeds. Metabolism of clodinafop-propargyl in wheat proceeded through deesterification to the herbicidally active acid, followed by hydroxylation and ether cleavage to yield 2-[4-(6-hydroxy-5-chloro-3-fluoro-2-pyridinyloxy)phenoxy] propionic acid and 2-(4-hydroxyphenoxy)propionic acid, respectively. All metabolites were subject to carbohydrate conjugation. In excised wheat leaves, rapid deesterfication occurred, while all subsequent metabolic steps where significantly enhanced by the safener cloquintocet-mexyl (Kreuz et al., 1991). In leaves of *Alopecurus myosuroides* and *Lolium rigidum*, the readily formed free acid of clodinafop-propargyl was slowly converted to a major metabolite that was identified by mass spectrometry, ^{1}H-nmr and chemical synthesis as the ester conjugate of the herbicide acid with malate (Kreuz et al., unpublished results). No oxidative metabolism of clodinafop-propargyl was detected in these weed species. The rates of deesterification of clodinafop-propargyl and re-esterification with malate were not influenced in these weeds by the safener cloquintocet-mexyl. Thus, the metabolic pathway conferring moderate herbicide tolerance to wheat in the absence of cloquintocet-mexyl and which is enhanced by the safener to confer full tolerance is completely absent in these susceptible weeds.

CONCLUSION

Herbicide safeners act at multiple sites of herbicide metabolism and detoxification pathways in plants by enhancing oxidative reactions, glucose conjugation, glutathione conjugation, and glutathione biosynthesis. There are indications that induction of metabolism is exerted at the level of transcription of genes coding for herbicide-metabolizing enzymes. Safeners appear to enhance, in a particular plant species, metabolic pathways that are already expressed at a certain constitutive level, rather than to induce qualitatively different reactions. The molecular mechanisms involved in these induction processes, however, still remain elusive and require further research.

REFERENCES

Amrein J; Nyffeler, A; Rufener J. (1989) CGA 184"927 +S: a new post-emergence grasskiller for use in cereals. *Brighton Crop Protection Conference Weeds 1989*, 1, 71-76

Bellus, D (1991) Development of modern plant protection products: why and how.*Chimia*, 45, 154-159

Brown, H.M.; Dietrich, R.F.; Kenyon, W.H.; Lichtner, F.T. (1991) Prospects for the biorational design of crop selective herbicides. Brighton Crop Protecnon Conference -Weeds 1991, 2, 847-856

Dean, J.V.; Gronwald, J.W.; Eberlein, C.V. (1990) Induction of glutathione S-transferase isozymes in sorghum by herbicide antidotes. Plant Physiology, 92, 467-473.

Donaldson, R.P.; Luster, D.G. (1991) Multiple forms of plant cytochromes P-450. PlantPhysiology, 96, 669-674.

Farago, S.; Brunold, C. (1990) Regulation of assimilatory sulfate reduction by herbicide safeners in Zea mays L. Plant Physiology, 94, 1808-1812.

Farago, S.; Kreuz, K.; Brunold, C. (1993) Decreased glutathione levels enhance the susceptibility of maize seedlings to metolachlor. Pesticide Biochemistry and Physiology, 47 (3), 199-205

Farago, S.; Brunold, C. (1994) Regulation of thiol contents in maize roots by inetrmediates and effectors of glutathione synthesis. Journal of Plant Physiology,144, 433-437

Fonne-Pfister, R.; Gaudin, J.; Kreuz, K.; Ramsteiner, K.; Ebert, E. (1990) Hydroxylation of primisulfuron by an inducible cytochrome P450-dependent monooxygenase system from maize. Pesticide Biochemistry and Physiology, 37, 165-173.

Frear, D.S.; Swanson, H.R.; Thalacker, F.W. (1991) Induced microsomal oxidation of diclofop, triasulfuron, chlorsulfuron, and linuron in wheat. Pesticide Biochemistry and Physiology, 41, 274-287.

Frear, D.S.; Swanson, H.R.; Tanaka, F.S. (1993) Metabolism of flumetsulam (DE-498) in wheat, corn, and barley. Pesticide Biochemistry and Physiology 45, 178-192.
Fuerst, E.P.; Gronwald, J.W. (1986) Induction of rapid metabolism of metolachlor in sorghum (Sorghum bicolor) shoots by CGA-92194 and other antidotes. Weed Science, 34, 354-361.
Fuerst, E.P.; Lamoureux, G.L. (1992) Mode of action of the dichloroacetamide antidote BAS 145-138 in corn. II. Effects on metabolism, absorption, and mobility of metazachlor. Pesticide Biochemistry and Physiology, 42, 78-87.
Fuerst, E.P.; Irzyk, G.P.; Miller, K.D. (1993) Partial characterization of glutathione S-transferase isozymes induced by the herbicide safener benoxacor in maize. Plant Physiology, 102, 795-802.
Gronwald, J.W.; Fuerst, E.P.; Eberlein, C.V.; Egli, M.A. (1987) Effect of herbicide anddotes on glutathione content and glutathione S-transferase activity of sorghum shoots. Pesticide Biochemistry and Physiology, 29, 66-76.
Hatzios, K.K.; Hoagland, R.E. (Eds) (1989) Crop Safeners for Herbicides: Development. Uses, and Mechanisms of Action, San Diego: Academic Press, 400 pp.
Hatzios, K.K. (1991) An overview of the mechanisms of action of herbicide safeners. Zeitschrift fuer Naturforschung, 46c, 819-827.
Hinchee, M.A.W.; Padgette, S.R.; Kishore, G.M.; Delannay, X.; Fraley, R.T. (1993) Herbicide-tolerant crops. In: Transgenic Plants. Volume 1, Engineering and Utilization, S. Kung and R. Wu (Eds), San Diego: Academic Press, pp. 243-263.
Khalifa, M.A.; Lamoureux, G.L. (1990) The effect of BASF 145 138 safener on the secondary and tertiary steps of propachlor and metolachlor metabolism in corn. Seventh International Congress of Pesticide Chemistry (IUPAC), 2, H. Frehse, E.
Kesseler-Schmitz and S. Conway (Eds), p. 172.
Komives, T.; Komives, V.A.; Balazs, M.; Dutka, F. (1985) Role of glutathione-related enzymes in the mode of action of herbicide antidotes. 1985 British Crop Protection Conference- Weeds, 3, 1155-1162.
Kreuz, K.; Gaudin, J.; Ebert, E. (1989) Effects of the safeners CGA 154281, oxabetrinil and fenclonm on uptake and degradation of metolachlor in corn (Zea mays L.) seedlings. Weed Research, 29, 399 405.
Kreuz, K.; Gaudin, J.; Stingelin, J.; Ebert, E. (1991) Metabolism of the aryloxyphenoxypropanoate herbicide, CGA 184927, in wheat, barley and maize: differential effects of the safener, CGA 185072. Zeitschrift fuer Naturforschung, 46c, 901-905
Lamoureux, G.L.; Shimabukuro, R.H.; Frear, D.S. (1991) Glutathione and glucoside conjugation in herbicide selectivity. In: Herbicide Resiscance in Weeds and Crops, J.C. Caseley, G.W. Cussans and R.K. Atkin (Eds), Oxford: Butterworth-Heinemann pp. 227-261.
Lamoureux, G.L.; Rusness, D.G. (1992) The mechanism of action of BAS 145 138 as safener for chlrimuron ethyl in corn: effect on hydroxylation, glutathione conjugation, glucoside conjugation, and acetolactate synthase. Pesticide Biochemstry and Physiology, 42, 128-139.
LeBaron, H.M.; McFarland, J.E.; Simoneaux, B.J.; Ebert, E. (1988) Metolachlor. In:Herbicides. Chemistry, Degradation, and Mode of Action. Volume 3, P.C. Kearney and D.D. Kaufman (Eds), New York: Marcel Dekker, pp. 335-382.
Martinoia, E.; Grill, E.; Tommasini, R.; Kreuz, K.; Amrhein, N. (1993) ATP-dependent glutathione S-conjugate export pump in the vacuolar membrane of plants. Nature, 364, 247-249.
Moreland, D.E.; Corbin, F.T.; McFarland, J.E. (1993) Effects of safeners on the oxidation of multiple substrates by grain sorghum microsomes. Pesticide Biochemistry and Physiology, 45, 43-53.
Owen, W.J. (1987) Herbicide detoxification and selectivity. 198 British Crop Protection Conference - Weeds, 1, 309-318.
Peek, J.W.; Collins, H.A.; Porpiglia, P.J.; Ellis, J.F.; Maurer, W. (1988) CGA-154281- a new safener for improved herbicide tolerance in corn. Weed Science Society of America Abstracts, 28, 35.
Stephenson, G.R.; Yaacoby, T. (1991) Milestones in the development of herbicide safeners. Zeitschrift fuer Naturforschung, 4Cc, 794-797.
Timmerman, K.P. (1989) Molecular Characterization of corn glutathione S-transferase isozymes involved in herbicide detoxication. Physiologia Plantarum, 77, 465-471
Viger,P.R.; Eberlein, C.V.; Fuerst,E.P.; Gronwald, J.W. (1991) Effects of CGA 154281 and temperature on metolachlor absorption and metabolism, glutathione content, and glutathione S-transferase activity in corn (Zea mays). Weed Science, 39,324-328
Yaacoby,T.;Hall, J.C. Stephenson, G.R. (1991) Influence of fenchlorazole-ethyl on the metabolism of fenoxaprop-ethyl in wheat, barley, and crabgrass. Pesticide Biochemistry and Physiology, 41, 296-304.
Zimmerlin, A.;Duerst, F. (1992) Aryl hydroxylation of the herbicide diclofop by a wheat cytochrome P-450 monooxygenase. Substrate specificity and physiological activity. Plant Physiology, 100, 874-881.

Current Status of Herbicide-Resistant Weeds and Their Management Strategies

J. C. Cotterman
DuPont Agricultural Products, P.O. Box 30, Newark, Delaware 19714 U.S.A.

Abstract. Since the first reports of herbicide-resistant weeds in the 1960s, resistance has been confirmed in at least 100 species, affecting many diverse herbicide classes and modes of action. Resistant weeds have been identified worldwide, generally in continuous monoculture crop fields, or non-crop areas, where a single herbicide mode of action was used repeatedly. Resistance to triazines, which are Photosystem II inhibitors, was one of the first confirmed cases, and it is now the most prevalent type of herbicide resistance, with 58 resistant species. Fewer, but significant numbers of species have documented resistance to Photosystem I inhibitors, acetyl CoA carboxylase inhibitors, acetolactate synthase inhibitors, tubulin inhibitors, and auxin analogs, among others. Strategies to minimize and manage herbicide resistance focus on reducing selection by a single mode of action alone, and on depleting the weed population. A long-term, planned approach to weed management should integrate a variety of chemical and non-chemical weed control methods. Judicious selection of mixture, rotational, or sequential applications of herbicides with different modes of action should be implemented in conjunction with cultural practices to reduce production and dispersal of weed seeds. Competitive crop stands, weed-free seeds, crop rotation, tillage or cultivation, non-selective herbicides, grazing, delayed planting, clean machinery and equipment, and removal of weed seeds during harvest are examples of techniques that may be employed with selective herbicides to enhance the ability to manage weeds and maintain efficient crop production in the face of resistance.

Key words. herbicide-resistant weeds, resistance management strategies

Introduction

The evolution of herbicide resistance in weeds resulting from repeated herbicide applications was first reported in the 1960s (1). Since that time, the numbers of weed species, herbicide classes, and geographical areas affected by resistance have grown continually. Use of the same herbicide for several consecutive years characterizes the situations in which the first resistant weeds developed. After thirty years, and the development of thousands of additional resistance sites, it is still true that resistance generally occurs where the same herbicide, or herbicides with the same mode of action, are used to control the same weed for several years. Weed management strategies to avoid or delay the onset of resistance have been devised to reduce the intensity of selection that such mono-herbicide systems apply to weed populations, and to deplete the weed population by reducing seed production.

Current Status

The first reports of weed populations evolving herbicide resistance were of triazine-resistant common groundsel (*Senecio vulgaris* L.) (24) and 2,4-D-resistant wild carrot (*Daucus carota* L.) (29). Since then, at least 30 countries worldwide have reported one or more cases of resistance (15). Although species with resistance to members of various other herbicide classes have been documented (10), triazine resistance is the most prevalent with at least 58 resistant species identified (15). Significant numbers of species have developed resistance to other herbicide classes (Fig. 1) including acetolactate synthase (ALS) inhibitors, acetyl CoA carboxylase (ACCase) inhibitors, auxin analogs, Photosystem I (PS I) inhibitors, and tubulin inhibitors, as well as non-triazine Photosystem II (PS II) inhibitors.

In many of the cases studied so far, resistance is due to an alteration of the target site that renders it less susceptible to the herbicide (10). On this basis, selection for resistance to one member of a herbicide class often confers resistance to some or all other herbicides with the same mode of action. This phenomenon is known as target site cross resistance, and herbicides with different modes of action generally retain activity on such biotypes.

An important trend during the last decade has been the development of non-target site cross resistance and multiple resistance, best exemplified by blackgrass (*Alopecurus myosuroides* Huds.) in the United Kingdom and rigid ryegrass (*Lolium rigidum* Gaud.) in Australia (8). Biotypes of these species have evolved resistance to many herbicides from different chemical classes and having different modes of action, often without having been treated by some of the herbicides. The basis for resistance is one (non-target site cross resistance) or several (multiple resistance) resistance mechanisms. These biotypes can be especially problematic because of the limited number of selective herbicides still capable of controlling them.

Resistance Evolution

For resistance to evolve, genetic variation for the resistance trait(s) must exist within a population, and selection events must take place (17). Genetic variation for resistance probably arises from spontaneous gene mutation (12). There is no data to indicate that mutations result from herbicide application (10). The rate of resistance evolution depends on initial frequency of resistance alleles, mode of inheritance, relative fitness of the resistant and susceptible phenotypes, soil seed bank dynamics, and selection intensity (6, 17), with selection intensity having the greatest influence (12). Selection intensity on a particular weed by a given herbicide is determined by the intrinsic efficacy of the herbicide and the duration of its effect against that weed, coupled with its frequency of use.

Considering the components of selection intensity, as alluded to earlier, the majority of sites where herbicide resistance has developed are characterized by practices that imposed high selection intensity. These practices include:

- Reliance on a single herbicide mode of action in continuous monoculture, rotational cropping, or industrial use (such as roadsides or railroad rights-of-way)
- Use of herbicides with long residual activity (or high application rates that impart long residual) or frequent applications.

Specific examples of situations resulting in high selection intensity, and alternative weed management programs, will be described in a later section.

Compounding the issue of selection intensity is the wide range of inherent sensitivity of different weeds to the same herbicide and the fact that herbicide application rates are typically selected to control numerous species. Consequently, the recommended application rate may be considerably higher than the rate required to control the most sensitive weeds. Species in which resistance has evolved have generally been those that are highly sensitive to the selecting herbicide. Thus at recommended application rates they are exposed to very high selection intensity.

Once established, the spread of resistance is influenced by gene flow, through either pollen or seed dispersal. Aside from cytoplasmic inheritance of target-site triazine resistance, inheritance is by single, nuclear, dominant or semi-dominant genes in the majority of resistant biotypes where inheritance has been studied (4). This implies that pollen dispersal should be a key mechanism in resistance gene flow. However, though pollen movement is involved in spreading resistance for species with a high degree of cross-fertilization and with resistance mechanisms encoded by nuclear genes, seeds likely play a more important role in many instances (12), especially for long-distance dispersal (28). Many resistant species are prolific seed producers, and some have seed dispersal mechanisms that promote seed spread (25, 27). Furthermore, harvesting operations and farm implements contaminated with resistant seeds (or vegetative propagules) can increase dissemination of resistance. Therefore, prevention of seed production and dispersal is a key objective of resistance management programs.

Exceptions to the tendency for seed migration to be the major means of gene flow are blackgrass and rigid ryegrass. These species, in which cross- and multiple resistance have developed, are obligate cross pollinators and possess a high degree of genetic variability. It is hypothesized that cross-fertilization among survivors of herbicide applications in large populations results in the exchange of genes for several resistance mechanisms. Consequently, multiple mechanisms accumulate in individuals and populations (8, 23). For these species, pollen movement appears to play a substantial role in resistance spread.

Resistance Management Strategies

From the previous discussion of factors that affect the rate of resistance evolution and spread, it is clear that strategies to minimize and manage resistance must focus on reducing selection by a single herbicide mode of action alone, and on limiting seed production. Not only are these among the most influential determinants, but they are also among the few factors over which a farmer can exert control. A long-term, planned approach that integrates a variety of chemical and non-chemical methods over multiple years of the rotation is key to successful weed management. Techniques to reduce selection pressure include (6, 12, 16):

- Rotating crops in conjunction with rotating herbicide modes of action
- Using mixtures or sequential treatments of herbicides with different modes of action

- Using shorter-residual herbicides
- Limiting the number of treatments per crop with the same mode of action for control of the same species.

When choosing the herbicide(s) with alternative modes of action for mixture, sequential, or rotational treatments with a particular herbicide, the optimal partner with respect to resistance management is one with a similar weed control spectrum and residual activity as the primary herbicide. In addition, the application rate of the partner herbicide should be sufficient to provide effective control of the target species. Regarding the selection of rotational crops, one should consider crops that would allow the use of selective herbicides that are still effective against resistant biotypes that may have been selected by the use of a previous herbicide.

Another means by which herbicides with alternate modes of action may be introduced into the cropping system is through the use of herbicide-resistant crops (5). For example, as crops resistant to glyphosate and glufonsinate become available, growers may break the selection cycle for resistance to selective herbicides by incorporating these non-selective herbicides (with appropriate resistant crop varieties) into their in-crop weed management program.

A wide variety of methods may be used before, during, or after the cropping season, or during a non-crop part of the rotation, to deplete the seedbank and limit new weed seed production (16, 19, 23). Many of these methods are non-selective and thus control resistant and susceptible biotypes equally. A partial list of measures to prevent spread of resistance by seeds includes:

- Using tillage or cultivation before or after the crop or during a fallow period
- Using non-selective herbicides before or after the crop or during a fallow period
- Delaying planting so that early germinating weeds can be controlled by cultivation or non-selective herbicides
- Making a late season herbicide application to control late maturing weed species
- Producing competitve crop stands
- Using mulches
- Cutting a crop for hay, silage, or green manure before weed seed production
- Rotating to pasture and grazing before weed seed production.

In addition, consideration should be given to rotating to crops grown in different seasons. "Shifting" the cropping season may provide opportunities during the "new" off-season to control problem weeds of the standard crop by alternative herbicides or non-selective methods that are not practical in the cropping season.

Measures should also be taken to minimize weed seed dispersal which may be accomplished by:

- Planting weed-free seeds
- Cleaning farm machinery and implements
- Collecting and removing weed seeds during the harvesting operation (if seeds are not shed at maturity)
- Burning pastures or crop and weed residues to destroy seeds.

The above lists are not intended to be comprehensive. Rather, they should be viewed as providing ideas to form the basis of an integrated weed management plan that is customized for the prevailing local environmental, economic, and cultural conditions, as well as the crop and weed biological characteristics. Such conditions vary dramatically from place to place, as do exploitable characteristics of target weeds. It is therefore imperative that management strategies be devised on a local, and even a field-by-field basis.

Fitness Considerations

Empirical models indicate that if the resistant phenotype is associated with reduced fitness (in the absence of the selecting herbicide), resistance evolution will be slower than if the resistant and susceptible phenotypes have similar fitness (6,18). The relative fitness of the resistant and susceptible phenotypes can also influence the effectiveness of some resistance management strategies. Specifically, models predict that rotating herbicides will be more effective in slowing the progression toward resistance or in hastening the reversion to susceptibility (when use of the selecting herbicide is discontinued) when the resistant is less fit than the susceptible phenotype (6, 12, 18). The basis for these effects is that in the absence of the selecting herbicide, the proportion of the resistant phenotype in the population will decline due to its inferior competitive ability (fitness).

Substantially reduced fitness has been clearly demonstrated in several species with target-site resistance to triazines (11), and it has probably resulted in a slower progression to resistance than would be predicted based on only selection intensity and initial frequency. Fitness has not been studied as exhaustively for resistance to other modes of action as it has been for triazine resistance. However, from the available results, there does not appear to be a consistent fitness disadvantage in other resistant biotypes (11, 25). In particular, studies of fitness components in biotypes resistant to ALS inhibitors (25), ACCase inhibitors (30), or triallate and difenzoquat (21) have not revealed consistent fitness penalties compared to susceptible biotypes. Findings in studies of weeds resistant to dinitroanilines (tubulin inhibitors) and PS I inhibitors have been mixed, and they neither support nor refute the hypothesis of a general tendency for reduced fitness in resistant biotypes (11). Further, inherent intraspecific variation and selection by environmental conditions and cultural practices for specific traits may compensate for fitness effects associated with herbicide resistance in a field environment (11). Consequently, with the exception of target-site triazine resistance, when rotating to herbicides with a different mode of action, the expected effect will be a delay in resistance evolution proportional to the number of years away from the herbicide of interest. An enhanced delay, greater than the proportion of "off years", will occur only if fitness of the resistant plants is low in the off years (i.e. in the absence of selection by the herbicide of interest) (6).

Increased sensitivity of resistant plants to alternative herbicides, or negative cross resistance, can further delay resistance development or speed the return to a largely susceptible population (6). This phenomenon may not be widely applicable, however, as most examples of negative cross resistance so far reported have been among triazine-resistant plants (6), just as is true for reduced fitness (11).

Practical Examples Of Resistance Management

Resistance managment techniques have been proposed largely based on theory and empirical modelling. Few experiments have been conducted to systematically study the benefits of employing resistance management strategies, or to compare the efficacy of various strategies in delaying the onset of resistance or in managing it once it has evolved. Therefore, it is instructive to review some examples of actual farming situations in which contrasting weed control practices were used and had different results in terms of resistant weed development.

Perhaps the first and most obvious example is that of triazine resistance. Beginning in the 1960s, triazine resistance has developed extensively, and sometimes relatively rapidly (e.g. 6-10 years), in maize (*Zea mays* L.) monoculture, nurseries, orchards, and non-crop areas worldwide, where triazines were used repeatedly and exclusively for weed control (1, 7). In stark contrast is the fact that triazines have been used on other extensive areas of maize for over 30 years without resistance occurring (1, 6). The likely reason for this difference is that in the latter areas, several of the methods that we have listed as resistance management strategies have been typical of crop culture for many years. Maize is regularly rotated with other crops (e.g. soybeans (*Glycine max* (L.) Merr.) in the U.S. Midwest), numerous alternative herbicides with different modes of action are used in maize as well as the rotational crop(s), and tillage or interrow cultivation is practiced. Comparing the resistance outcome of the two situations offers clear support for crop rotation and the use of a variety of herbicide modes of action.

A similar example is that of the development of resistance to ALS inhibitors in broadleaf weeds of cereal crops in North America but not in Europe (2, 25). Cereal culture in much of Canada and the northern U.S. is characterized by monoculture, relatively few effective alternatives to ALS inhibitor herbicides for broadleaf weed control, and environmental conditions that favor long residual activity of some ALS inhibitors. Hundreds of sites of resistant kochia (*Kochia scoparia* (L.) Schrad.) have been confirmed among the cereal growing areas of the northern U.S. and Canada (2, 25). On the other hand, in northern Europe, cereals are generally grown in rotation with a diversity of crops. Further, a variety of herbicides, herbicide mixtures, and sequential treatments are available for use, not only in cereals, but also in the rotational crops. Consequently, to date there is only one confirmed case of resistance in a broadleaf weed to ALS inhibitors (2, 25) even though ALS inhibitors for cereals have been available in Europe nearly as long as in North America. Significantly, this resistant chickweed (*Stellaria media* (L.) Vill.) developed in a Danish field in which spring barley (*Hordeum vulgare* L.) had been grown continuously and treated with an ALS inhibitor alone for five years (13). Again, this comparison supports the validity of crop and herbicide rotation and herbicide mixtures for delaying resistance.

A third example also highlights the importance of rotating herbicide modes of action along with crop rotation. ACCase inhibitors are used only for grass control, and dinitroanilines are used for grass and broadleaf control. Due to their versatility, members of both of these classes may be used in grain and oilseed crops. In some areas of western Canada, dinitroanilines have been used annually on the same field for control of green foxtail (*Setaria viridis* (L.) Beauv.) for more than 15 years, in spite of rotating crops. The result has been widespread green foxtail resistance to dinitroanilines in these areas (20, 26). Similarly, ACCase inhibitors have been used annually as the exclusive control of wild oat (*Avena fatua*

L.) in some fields in cereal-oilseed rotations. Predictably, the outcome has been the development of wild oats resistant to ACCase inhibitors (3, 9). Although dinitroanilines and ACCase inhibitors are also used for grass control in rotated crops (i.e. maize/soybeans) in the U.S., resistance has not been observed under these circumstances. A possible basis for this absence of resistance is that neither of these two classes of herbicides with different modes of action is used as the sole grass control agent throughout the rotation. Maize-selective ACCase inhibitors are not available, and herbicide mixtures and sequential treatments incorporating grass activity from different modes of action are currently the norm in both maize and soybeans. Thus selection from a single mode of action alone is minimized.

The final example to be discussed emphasizes the importance of carefully selecting partner herbicides for mixture, sequential, or rotational treatments. It is critical that the partner herbicides be active on the species of most concern for resistance development and that they be used at rates that provide effective control. Resistance to the ALS inhibitor bensulfuron methyl developed after 4 years of its continuous use in monoculture rice (*Oryza sativa* L.) in California, U.S. and New South Wales, Australia (2, 22, 25). Smallflower umbrella sedge (*Cyperus difformis* L.), an annual sedge, developed resistance in California and New South Wales. California arrowhead (*Sagittaria montevidensis* spp. *calycina*), an annual broadleaf, developed resistance in California. Both of these weeds are very sensitive to bensulfuron methyl and are not controlled by molinate, the predominant partner that was used with bensulfuron methyl. In addition, due to various issues such as water quality and drift potential, few herbicides with other modes of action are available for annual broadleaf and sedge control in rice in California or New South Wales. Under these conditions, selection intensity for resistance was high and widespread. In contrast, although rice is also grown in monoculture in Japan, the selection intensity for resistance to the ALS inhibitors is generally low in this country. The reason for the reduced selection intensity is that in Japan, nearly all rice ALS inhibitors are sold in combinations with herbicides having other modes of action and weed control spectra that overlap the ALS inhibitors. Additionally, the mixtures are frequently applied in sequence with other non-ALS inhibitor herbicides. ALS inhibitors have been marketed in Japan since 1987, with the first being bensulfuron methyl. Weed management methods in practice in most of Japan during that time have minimized the potential for resistance development. However, the occurrence of resistance of paddy weeds to ALS inhibitors in California and New South Wales underscores the need for selection of partner herbicides with overlapping weed control spectra and alternative modes of action for mixtures or sequential treatments.

Paradoxes In Resistance Management

The already complex task of developing effective resistance management strategies is complicated by the existence of several apparent inconsistencies between recommended methods and current agricultural realities. Several examples follow:

- Recommendation: Use tillage or cultivation.
  Inconsistency: The trend is toward reduced- or no-till practices to conserve soil, water, and energy resources.

- Recommendation: Removal or burning of crop residues or pastures.
  Inconsistency: Trend is to maintain residues for soil conservation; burning is banned in some areas due to air quality concerns.

- Recommendation: Delay planting.
  Inconsistency: Delayed planting often results in less competitive crop stands, which is detrimental to weed control, and reduced yield.

- Recommendation: Rotate crops.
  Inconsistency: Government programs often indirectly encourage monoculture cropping.

- Recommendation: Use herbicide-resistant crops.
  Inconsistency: Repeated use of a single mode of action alone, even with such herbicides as glyphosate or glufosinate, may lead to evolution of resistance or a shift in the population from sensitive to less sensitive species.

The benefits and vulnerabilities of a multitude of factors must be balanced when a comprehensive weed management program is constructed. This is a compelling reason to promote the cooperation of all members of the agricultural community: farmers, academia, government, and industry, in managing resistance to maintain tools for efficient crop production.

Prospects For The Future

Currently many chemical and non-chemical weed control tools are available to enable most farmers to adopt integrated weed management programs that will allow efficient crop production and delay the onset of resistance. However, agricultural realities are constantly changing. Regulatory pressures, that for a variety of reasons result in the removal of current herbicides from the marketplace, reduce the number of herbicide options. Furthermore, increasing hurdles for the commercialization of new herbicides slow the rate of introduction of new products and, most importantly, new modes of action. Several new products (e.g. new ACCase inhibitors and ALS inhibitors) have expanded the number of crops in which the same mode of action may be used. Farmers should be aware of the mode of action of herbicides they use and plan for rotating modes of action as well as crops. Herbicide-resistant crops introduce another potentially complicating factor for resistance management. As they become more widely adopted, they should be incorporated into the overall weed management strategy in a way that does not promote continuous reliance on a single mode of action for control of key target weeds. Further, additional methods such as biological control and herbicide synergists may become more available in the future. To continue to meet weed management challenges, farmers will need to be alert to changes in their weed populations, stay well informed and adaptable to new management techniques, and work closely with local extension, academics, and retailers to maintain efficient, productive operations.

Acknowledgement: The author thanks Drs. J. L. Saladini and L. L. Saari for reviewing the manuscript.

References

1. Bandeen, J.D., G.R. Stephenson, and E.R. Cowett. 1982. Discovery and distribution of herbicide-resistant weeds in North America. In H.M. LeBaron and J. Gressel (Eds.), Herbicide Resistance in Plants. N.Y.: John Wiley & Sons, Inc. (pp. 9-30).

2. Brown, H.M. and J.C. Cotterman. 1994. Recent advances in sulfonylurea herbicides. In J. Stetter (Ed.), Herbicides Inhibiting Branched Chain Amino Acid Biosynthesis. Berlin: Springer-Verlag (pp. 47-81).

3. Devine, M.D. and R.H. Shimabukuro. 1994. Resistance to acetyl-coenzyme A carboxylase inhibiting herbicides. In S.B. Powles and J.A.M. Holtum (Eds.), Herbicide Resistance in Plants: Biology and Biochemistry. Boca Raton: Lewis Publishers (pp. 141-169).

4. Gasquez, J. 1995. Inheritance of herbicide resistance within weeds. Proceedings of the International Symposium on Weed and Crop Resistance to Herbicides. Kluwer Academic Press (In press).

5. Gressel, J. 1988. Wheat Herbicides: The Challenge of Emerging Resistance. Reading: Biotechnology Affiliates (247 pp.).

6. Gressel, J. and L.A. Segel. 1990. Herbicide rotations and mixtures. In M.B. Green, H.M. LeBaron, and W.K. Moberg (Eds.), Managing Resistance to Agrochemicals: From Fundamental Research to Practical Strategies. Washington, D.C.: American Chemical Society (pp. 430-458).

7. Gronwald, J.W. 1994. Resistance to Photosystem II inhibiting herbicides. In S.B. Powles and J.A.M. Holtum (Eds.), Herbicide Resistance in Plants: Biology and Biochemistry. Boca Raton: Lewis Publishers (pp. 27-60).

8. Hall, L.M., J.A.M. Holtum, and S.B. Powles. 1994. Mechanisms responsible for cross resistance and multiple resistance. In S.B. Powles and J.A.M. Holtum (Eds.), Herbicide Resistance in Plants: Biology and Biochemistry. Boca Raton: Lewis Publishers (pp. 243-261).

9. Heap, I.M., B.G. Murray, H.A. Loeppky, and I.N. Morrison. 1993. Resistance to aryloxyphenoxypropionate and cyclohexanedione herbicides in wild oat (*Avena fatua*). Weed Sci. 41: 232-238.

10. Holt, J.S., S.B. Powles, and J.A.M. Holtum. 1993. Mechanisms and agronomic aspects of herbicide resistance. Annu. Rev. Plant Physiol. Plant Mol. Biol. 44: 203-229.

11. Holt, J.S. and D.C. Thill. 1994. Growth and productivity of resistant plants. In S.B. Powles and J.A.M. Holtum (Eds.), Herbicide Resistance in Plants: Biology and Biochemistry. Boca Raton: Lewis Publishers (pp. 299-316).

12. Jasieniuk, M. and B.D. Maxwell. 1994. Population genetics and the evolution of herbicide resistance in weeds. Phytoprotection 75 (Suppl.): 25-35.

13. Kudsk, P., S.K. Mathiassen, and J.C. Cotterman. 1995 Sulfonylurea resistance in *Stellaria media* [L.] Vill. Weed Res. 35: In Press.

14. LeBaron, H.M. 1991. Distribution and seriousness of herbicide-resistant weed infestations worldwide. In J.C. Caseley, G.W. Cussans, and R.K. Atkin (Eds.), Herbicide Resistance in Weeds and Crops. Oxford: Butterworth-Heinemann, Ltd. (pp. 27-43).

15. LeBaron, H.M. 1992. Unpublished data. Ciba-Geigy Corporation.

16. Matthews, J.M. 1994. Management of herbicide resistant weed populations. In S.B. Powles and J.A.M. Holtum (Eds.), Herbicide Resistance in Plants: Biology and Biochemistry. Boca Raton: Lewis Publishers (pp. 317-335).

17. Maxwell, B.D. and A.M. Mortimer. 1994. Selection for herbicide resistance. In S.B. Powles and J.A.M. Holtum (Eds.), Herbicide Resistance in Plants: Biology and Biochemistry. Boca Raton: Lewis Publishers (pp. 1-25).

18. Maxwell, B.D., M.L. Roush, and S.R. Radosevich. 1990. Predicting the evolution and dynamics of herbicide resistance in weed populations. Weed Technol. 4: 2-13.

19. Martin, R.J. and W.L. Felton. 1993. Effect of crop rotation, tillage practice, and herbicides on the population dynamics of wild oats in wheat. Australian J. Experimental Agriculture 33: 159-165.

20. Morrison, I.N., B.G. Todd, and K.M. Nawolsky. 1989. Confirmation of trifluralin-resistant green foxtail (*Setaria viridis*) in Manitoba. Weed Technol. 3: 544-551.

21. O'Donovan, J.T., R.E. Blackshaw, K.N. Harker, D. Derksen, and A.G. Thomas. 1995. Relative seed germination and growth of triallate/difenzoquat susceptible and resistant wild oat (*Avena fatua*) populations. Proceedings of the International Symposium on Weed and Crop Resistance to Herbicides. Kluwer Academic Press (In press).

22. Pappas-Fader, T., J.F. Cook, T. Butler, P.J. Lana, and J. Hare. 1993. Resistance of California arrowhead and smallflower umbrella sedge to sulfonylurea herbicides. Proceedings of the Western Society of Weed Science 46: p. 76.

23. Powles, S.B. and J.M. Matthews. 1992. Multiple herbicide resistance in annual ryegrass (*Lolium rigidum*): A driving force for the adoption of integrated weed management. In I. Denholm, A.L. Devonshire, and D.W. Hollomon (Eds.), Resistance '91, Achievements and Developments in Combatting Pesticide Resistance. London: Elsevier Science Publishers (pp. 75-88).

24. Ryan, G.F. 1970. Resistance of common groundsel to simazine and atrazine. Weed Sci. 18: 614-616.

25. Saari, L.L., J.C. Cotterman, and D.C. Thill. 1994. Resistance to acetolactate synthase inhibiting herbicides. In S.B. Powles and J.A.M. Holtum (Eds.), Herbicide Resistance in Plants: Biology and Biochemistry. Boca Raton: Lewis Publishers (pp. 83-139).

26. Smeda, R.J., and K.C. Vaughn. 1994. Resistance to dinitroaniline herbicides. In S.B. Powles and J.A.M. Holtum (Eds.), Herbicide Resistance in Plants: Biology and Biochemistry. Boca Raton: Lewis Publishers (pp. 215-228).

27. Stallings, G.P., D.C. Thill, C.A. Mallory-Smith, and L.W. Lass. 1995. Plant movement and seed dispersal of Russian thistle (*Salsola iberica*). Weed Sci. 43: 63-69.

28. Stallings, G.P., D.C. Thill, C.A. Mallory-Smith, and B. Shafii. 1995. Pollen-mediated gene flow of sulfonylurea-resistant kochia (*Kochia scoparia*). Weed Sci. 43: 95-102.

29. Whitehead, C.W. and C.M. Switzer. 1963. The differential response of strains of wild carrot to 2,4-D and related herbicides. Can. J. Plant Sci. 43: 255-262.

30. Wiederholt, R.J. and D.E. Stoltenberg. 1995. Productivity and intraspecific competitive ability of a large crabgrass [*Digitaria sanguinalis* (L.) Scop.] accession resistant to acetyl-coenzyme A carboxylase inhibitors. Proceedings of the Weed Science Society of America 35: p. 46.

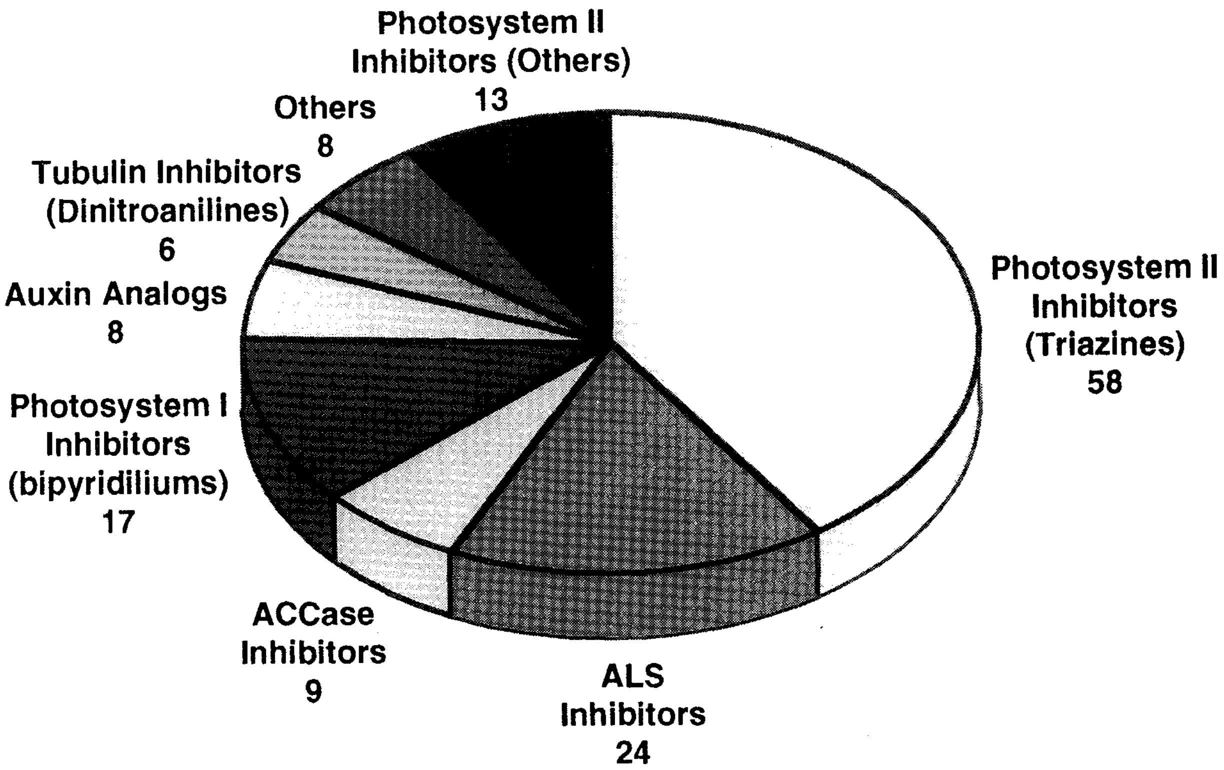


Figure 1. Worldwide distribution of herbicide resistance in weeds: number of species resistant to each herbicide class. Thirty countries reported occurrence of one or more resistant weed species (3, 10, 14, 15, 25, 26).

Current and Future Herbicide Risk Assessment in Europe and United States

William L. Chen, Ph.D., Global Regulatory, Toxicology and Environmental Chemistry, DowElanco, 9330 Zionsville Road, Indianapolis, IN 46268-1054 U.S.A.

Abstract. The risk assessment process offers regulators, registrants, public interest groups and users a means of weighing apparent health and environmental effects of pesticides (herbicides) and other chemicals, and measuring their safety for use. This paper examines three key areas of risk assessment: (1) Maximum Tolerated Dose (MTD), (2) Cancer Classification and Risk Assessment, and (3) Ecological Risk Assessment. The American, European and International approaches in these important areas are compared and discussed in light of the current scientific knowledge.

Key words. risk assessment, herbicide, global harmonization

Introduction

Pesticide (herbicide) risk assessment practices in the United States and Europe have changed dramatically during the past 10 years since the adoption of quantitative procedures that link experimental hazards identified in animals and plant species with human or environmental exposure from a variety of sources, including air, water, soil, food and the workplace. Herbicide risk assessment and risk management comprise dynamic processes that can be used to weight scientific evidence in order to formulate regulatory policy for the protection of human health and the environment.

All herbicides, because of their intended use, are toxic to some form of life. Risk assessments are, therefore, necessary to estimate a level of human or environmental exposure which will not result in adverse effects to human health or the environment. Risk assessment is an analytic process involving four integrated steps as recently identified by the European Union (EC, 1993) and the U.S. Government (U.S. National Research Council, 1983): (1) hazard identification, (2) dose-response assessment, (3) exposure assessment. and (4) risk characterization.

The basic process in human health risk assessment is to derive and compare the estimated human exposure (dose) with a no-observed-adverse-effect-level (NOAEL) for the most critical effect observed in human or animal toxicity studies conducted by a relevant route of exposure. Similarly, in ecological risk assessment, the process involves the derivation and comparison of the predicted environmental concentration (PEC) with the LC50 or no-observed-effect-concentration (NOEC), determined in aquatic, avian and other terrestrial species. The risk assessment process can either result in an adequate margin of safety (MOS) or an inadequate margin of safety. In the latter case, higher tier risk assessment or mitigation procedures, usually involving exposure refinement or reduction, will be employed.

Unfortunately, many different testing and evaluation guidelines have been adopted and implemented by various countries, creating significant differences in risk assessments and regulatory decisions on herbicides. The need for international harmonization in the field of pesticide (herbicide) health and environmental risk assessment has been recognized for a number of years. This recognition prompted the development, by the Food and Agriculture Organization (FAO), by the World Health Organization (WHO) and by the Organization for Economic Cooperation and Development (OECD), of recommendations for the harmonization of data requirements and risk assessment methodologies.

Recent efforts in national and international harmonization have provided a workable process by which the differences can be resolved in moving towards global harmonization of herbicide risk assessment and registration. This paper examines three key areas: (1) Maximum Tolerated Dose (MTD), (2) Cancer Classification and Risk Assessment, and (3) Ecological Risk Assessment. The American, European and International approaches in these important areas are compared in light of the current scientific knowledge.

Maximum Tolerated Dose (MTD)

Much of the controversy on MTD has been a result of inconsistencies in its definition and interpretation. These inconsistencies exist between the U.S. and most of the OECD countries. It is a source of disharmony between EC countries on one side and U.S. EPA on the other, in the registration and regulation of pesticides. It is therefore important to examine the MTD as it is defined and interpreted globally.

The OECD guideline for carcinogenicity studies gives this description of the MTD (OECD, 1987):

> The highest dose level should be sufficiently high to elicit signs of minimal toxicity without substantially altering the normal life span due to effects other than tumors. Signs of toxicity are those that may be indicated by alterations in certain serum enzyme levels or slight depression of body weight gain (less than 10 percent).

The EC Registration Directive (Directive 91/414/EEC, 1993 draft Annex II) describes the dose-selection process as follows (EC, 1993a):

> The doses tested, including the highest dose tested, must be selected on the basis of results of short-term testing and the level of possible human exposure, and where available at the time of planning the studies concerned, on the basis of metabolism and toxicokinetics data, such that at the highest dose, definite but minimal signs of toxicity are elicited (viz, slight depression in body weight gain), without causing tissue necrosis or metabolic saturation, and without altering normal life span due to effects other than tumors. Higher doses causing excessive toxicity are not considered relevant to evaluations to be made.

The World Health Organization (WHO) in discussing the selection of dose levels and the validity of MTD concept, states (IPCS, 1990):

> Results of studies at dose levels many orders of magnitude above the level of human exposure . . . (are of) little relevance. Instead of using the MTD to select the top dose level, the use of properly designed biotransformation studies over a range of doses (including human exposure level) may provide a more rational basis for dose selection in long term animal studies.

All three guidelines define minimal toxicity for selection of the highest dose. In contrast, the EPA takes the position of eliciting significant toxicity as its requirement for MTD (EPA, 1987):

> The highest dose to be tested in the oncogenicity study should be selected below a level which resulted in significant life-threatening toxicity in the subchronic study. The level should not be selected too far below a life-threatening level because the highest dose tested in the oncogenicity study should elicit significant toxicity without substantially altering the normal life span of the test species from effects other than tumor formation.

The consequences of selecting significant toxicity versus minimally toxic doses are enormous. As a result of differences in high dose selection, many rodent carcinogenicity studies were rejected by U.S. regulatory bodies, for not reaching MTD, even after they have been accepted by European and International agencies. The repeated studies add little knowledge in terms of real hazard identification or risk assessment of pesticides and hence are a waste of resources. The high doses themselves may produce tumors in animals which are not relevant to situations where humans are exposed to much lower concentrations. Differences in MTD may cause unwarranted concerns about residues allowed in food. This difference could give rise to potential trade barriers between nations and serve to increase the growing skepticism with which governments and scientists are regarded.

Recent efforts in harmonizing high dose selection or MTD have met with some success. The October 1993 consensus text of the International Conference on Harmonization (ICH) of Technical Requirements for the Registration of Pharmaceuticals for Human Use proposed five equally acceptable criteria for selecting the high dose (ICH, 1993): 1) dose-limiting pharmacodynamics, 2) a minimum of a 25-fold area-under-the-curve (AUC) ratio (rodent:human), 3) saturation of absorption, 4) maximum feasible dose, and 5) the MTD.

Another project underway is the international harmonization of risk assessment methodologies for carcinogens, mutagens, and reproductive toxins. Participants in this project include the WHO's International Program on Chemical Safety (IPCS), EC, OECD, and the U.S. EPA. Differences in approaches to high dose selection (MTD) hopefully will be harmonized in this process.

Cancer Classification and Risk Assessment

A recent survey of risk assessment methodologies practiced by OECD and selected non-OECD countries was conducted by IPCS (Dragula, 1994). While the linearized multistage extrapolation model is used by

U.S. in assessing cancer risks, most countries employed the No Observed Adversed Effect Levels (NOAELs) with safety factors for non-genotoxic carcinogenic risk assessment.

The U.S. EPA (EPA, 1986) assumption for all substances showing carcinogenic activity in animal experiments is that no threshold exists (or at least none can be demonstrated), so there is some risk with every exposure. Thus, the dose-response curve derived based on this assumption shows zero risk only at zero exposure. All other exposures entail some risk. All substances identified as Categories A or B, and some Category C carcinogens (see Table 1 for details on carcinogen classification) are subjected to the same linearized multistage extrapolation procedure in risk assessment. This is a conservative procedure used to estimate the hypothetical upper bounds on the cancer risk and cannot be related to expected disease incidence in an actual population. In fact, EPA generally attaches the following description to its risk estimates:

"The true value of the risk is unknown, and may be as low as zero."

Table 1

Human Classification of Carcinogens by EPA

A. Human Carcinogen
B. Probable Human Carcinogen
C. Possible
D. Inadequate Data
E. No Evidence (Negative)

A. B.	}	Risk Assessment
D. E.	}	No Risk Assessment

In EC and most OECD and non-OECD countries, carcinogens are divided into genotoxic and non-genotoxic categories. For genotoxic carcinogens, it is assumed that no threshold exists for these agents. Non-genotoxic carcinogens are treated as threshold toxicants. A NOAEL and safety factor are used to set allowable daily intakes (ADIs). The mechanisms of tumor induction are often investigated.

No linearized extrapolation models are used in cancer risk assessment. The U.K. described its rationale for not providing linearized mathematical model as follows (U.K., 1991): "The Committee does not support the routine use of quantitative (linearized model) risk assessment for chemical carcinogens. This is because the present models are not validated, are often based on incomplete or inappropriate data, are derived more from mathematical assumptions than from knowledge of biological mechanisms and, at least at present, demonstrate a disturbingly wide variation in risk estimates on the model adopted."

The linearized extrapolation model and the MTD used by U.S. EPA have also been severely criticized by others. Dr. Jay I. Goodman, in a paper in Molecular Carcinogenesis (1994), made the following statement (Ray, 1994):

"In freshman chemistry laboratory we are taught not to extrapolate beyond a standard curve because one quickly ends up in 'never-never land.' All too often the low-dose extrapolations from carcinogen bioassay results are based upon one data point, i.e., the estimated line is drawn from a single point, a practice that would not be deemed acceptable in a geometry class . . . The implicit assumptions underlying extrapolation from the MTD . . . do not appear to be valid. Therefore, both the criteria for selection of the high dose used and the default criteria that are employed for extrapolation from high-dose must be reevaluated in a critical manner."

Since 1986, our knowledge of carcinogenesis and risk assessment processes have continued to advance, leading U.S. EPA to initiate in 1994 (EPA, 1994) a revision of the 1986 Cancer Risk Assessment Guidelines (EPA, 1986). The major difference in the 1994 proposed revised guidelines compared with the 1986 guidelines concerns how evidence is weighed and used in support of decisions. Under the proposed revised guidelines, all scientific evidence will be used i.e. data on animal and/or human tumor effects, cancer mechanistic data and other key evidence. Risk characterization will include a robust qualitative and appropriate quantitative description of the conclusions instead of the current cancer classification scheme used by U.S. EPA (Table 1).

Other differences in the revised risk assessment process will include the following. The hazard identification step will include a description of the likelihood of hazard to humans and conditions of expression i.e. a consideration of the route, level, frequency and duration of human exposure. The use of a hazard narrative instead of the current alphanumeric classification. In the dose-response assessment step, biologically based model will be used as the first choice for fitting and extrapolation. Depending on the mechanism of carcinogenesis, linear default or threshold model will be used in assessing safety of carcinogens.

Ecological Risk Assessment

Ecological risk assessment will become nearly as important as human health risk is today. This is evident from the recent activities noted within the EC (EC, 1993a), U.S. EPA (EPA, 1993) and OECD (OECD, 1994) to develop various types of risk assessment schemes. A key ingredient of the ecological risk assessment process should be the ability to distinguish perceived risk from real risk. As outlined in Figure 1, the primary aspects of the process are to compare exposure values with toxicity endpoints in order to determine potential hazard. Then by a suitable means ecological significance is assessed. One fundamental aspect of risk (Figure 1) is the correlation between level of risk and the probability that a hazard might actually occur. The greater the probability, the greater the risk, and if too high, a risk management process takes over in order to mitigate risk back to an acceptable level. Therefore, key ingredients in ecological risk assessment are comparison of exposure to toxicity endpoints and evaluation of the probability that exposures will reach significant toxic levels.

To deal with the need for extensive data, computer assisted model simulation of pesticide (herbicide) movement is being used to develop the multiple sets of data and to serve as the basis for exposure refinement. Computer simulation is selected because it is a very cost effective way to generate the large data sets needed for risk refinement. With modern computers and computing tools it is now possible to generate thousands of PEC estimates at a fraction of the cost of a single field study. Field studies can still be utilized if desired but they take on much more meaning and value if designed to support and improve the modelling process.

From the above discussion, the following risk assessment or risk refinement scheme is presented (Figure 2):

Tier I. - Simple first estimation of PEC from simple inputs, consisting of application rate, and compared to toxicity endpoints. Very conservative assessment and serves to identify the species of concern.

Tier II. - Model simulation with standard worst-case scenarios of soil and weather as inputs. Scenarios defined probabilistically and are set to identify the 90th percentile PEC. The main purpose of this activity is to identify the use areas that have ecological concern. There may also be some activity to identify the benefits of mitigation.

Tier III. - Model simulation with many scenarios of soil and weather as inputs. The purpose is two fold: (1) to identify probabilistically the sensitive locations within a use area of concern, and (2) to evaluate mitigation/management techniques that can minimize level of risk.

Tier IV. - Landscape modelling to take into account the relationship between treated locations and sensitive habitats. All of the previous tiers assume habitat is at the edge of the treated area. This tier steps beyond and examines landscape factors that influence the ultimate PEC's for the sensitive habitat.

This tiered process of exposure refinement and thus risk refinement in ecological risk assessment is similar to that proposed recently in the U.S. by the Aquatic Risk Assessment and Management Dialogue Group (ARAMDG) (ARAMDG, 1994), and by FOCUS, the European modelling working group that has been working on ecological risk assessment for ground water.

Conclusion

The risk assessment process offers regulators, registrants, public interest groups and users a means of weighing apparent health and environmental effects of pesticides (herbicides) and other chemicals, and measuring their safety for use. All herbicides, because of their intended use, are toxic to some form of life. Risk assessments are, therefore, necessary to estimate a level of human or environmental exposure which will not result in adverse effects to human health or the environment. Risk assessment is an analytic process involving four integrated steps as recently identified by the European Union (EC, 1993) and the U.S. Government (U.S. National Research Council, 1983): (1) hazard identification, (2) dose-response assessment, (3) exposure assessment. and (4) risk characterization.

Unfortunately, many different testing and evaluation guidelines have been adopted and implemented by various countries, creating significant differences in risk assessments and regulatory decisions on herbicides. Recent efforts in national and international harmonization have provided a workable process by which the differences can be resolved in moving towards global harmonization of herbicide risk assessment and registration. This paper examines three key areas: (1) Maximum Tolerated Dose (MTD), (2) Cancer Classification and Risk Assessment, and (3) Ecological Risk Assessment. The American, European and International approaches in these important areas are compared in light of the current scientific knowledge.

Fig. 1. Environmental Risk Assessment Scheme

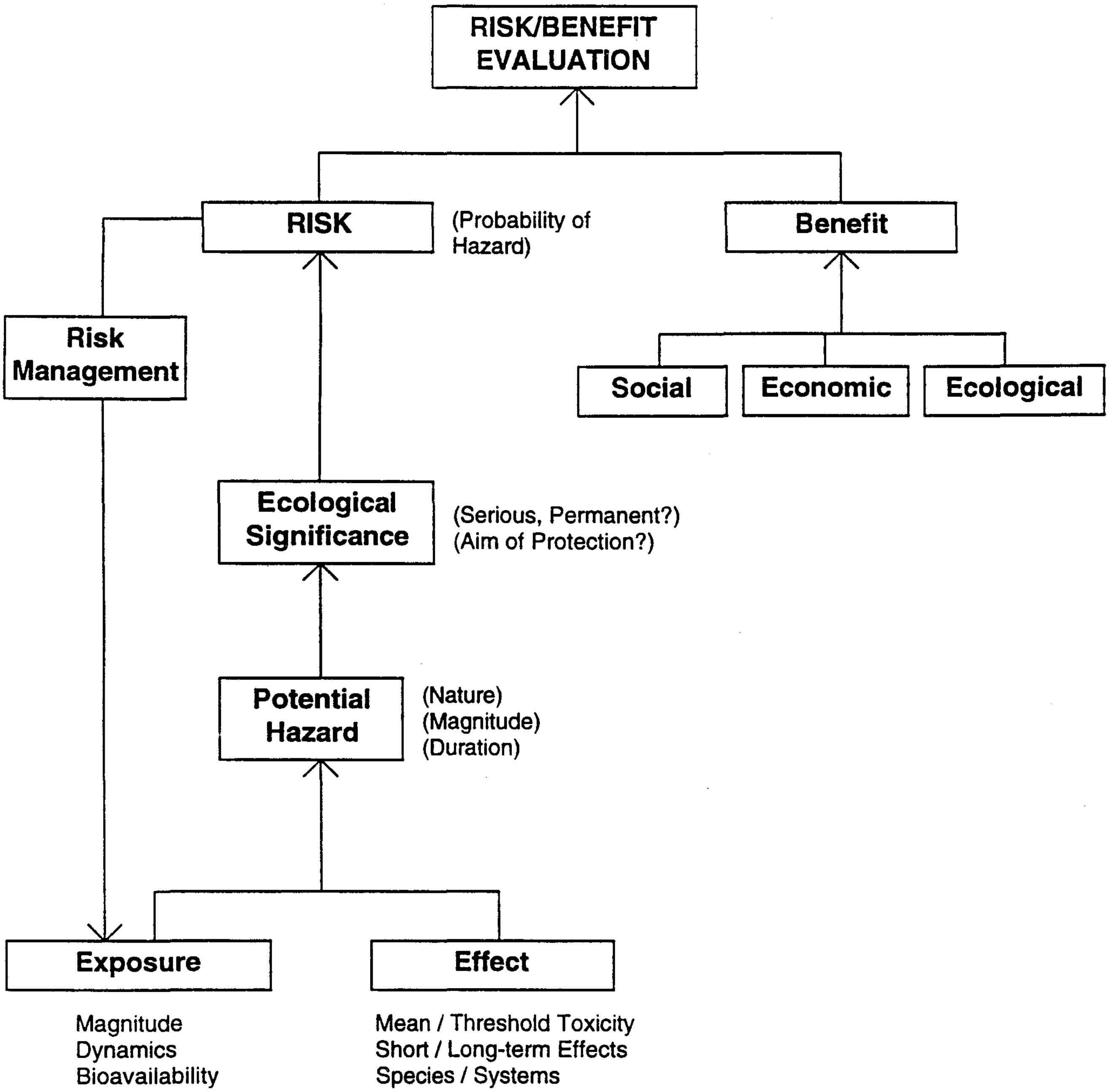
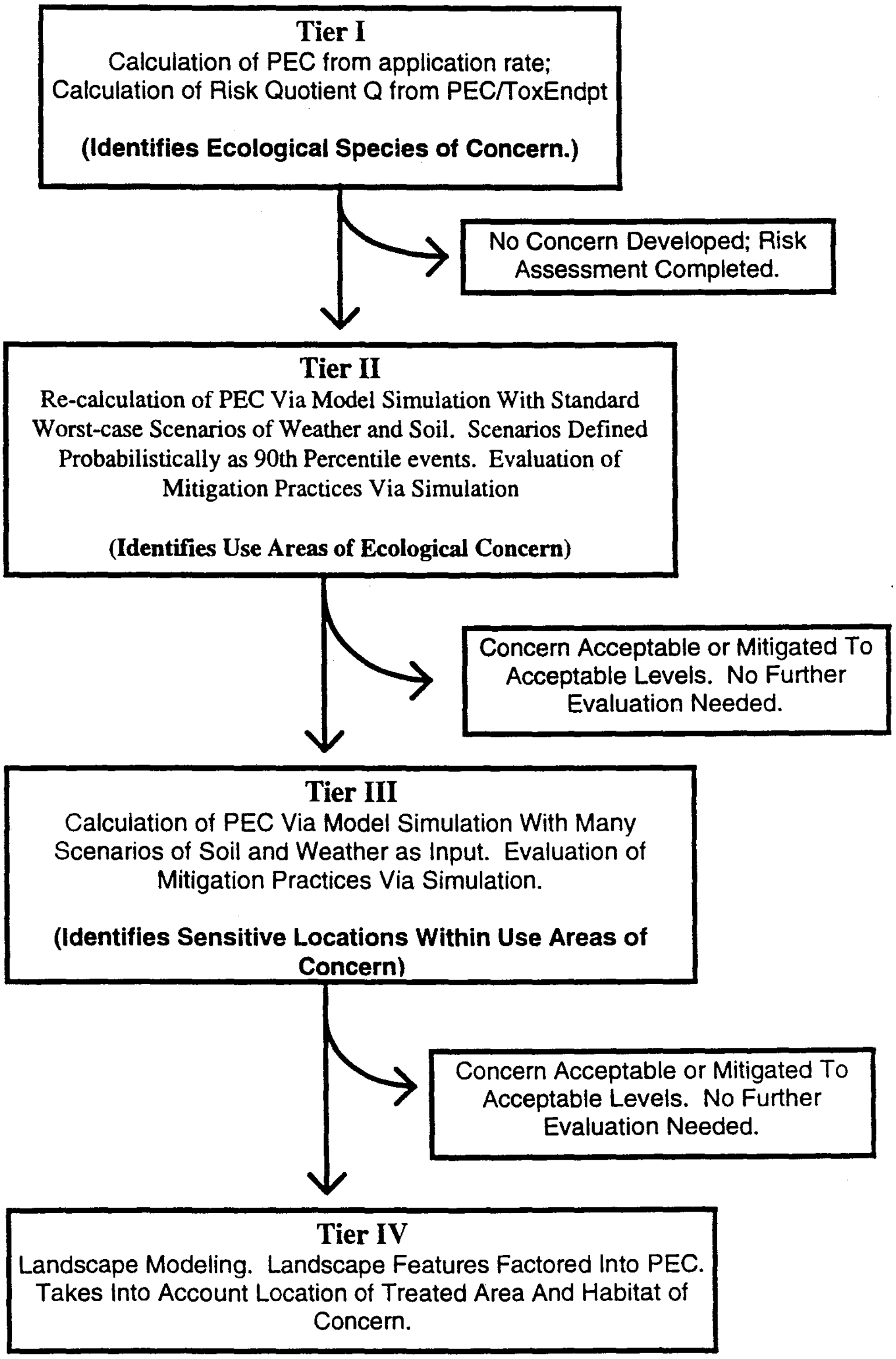


Fig. 2. Ecological Risk Refinement



References

ARAMDG, 1994, Final Report: Aquatic Risk Assessment and Mitigation Dialogue Group. Society of Environmental Toxicology and Chemistry (SETAC), SETAC Foundation for Environmental Education, Pensacola, Florida, November, 1994.

Dragula, 1994. Dragula, C.; Burin, G.; International Harmonization for the Risk Assessment of Pesticides: Results of an IPCS Survey; Reg. Tox. Pharm., 1994.

EC, 1993. Commission Directive 93/67/EEC of 20 July 1993. Official Journal of the European Communities No. L. 227/9.

EC, 1993a. EEC Directive 91/414. Council Directive Concerning the Placing of Plant Protection Products on the Market (regulating the registration of pesticides from July 1993 onwards), 1993.

EC, 1993b. Commission Directive of Laying Down the Principles for the Assessment of Risks to Man and the Environment of Substances Notified in Accordance with Council Directive 67/548/EEC, 1993.

EPA, 1986. U.S. Environmental Protection Agency (EPA), Guidelines for Cancer Risk Assessment. Fed. Reg. 51 (185): 33993 - 34003, 1986.

EPA, 1987. EPA Pesticide Assessment Guidelines, Subdivision F, Position Document - Selection of a Maximum Tolerated Dose (MTD) in Oncogenicity Studies. National Technical Information Service, Washington, DC, 1987.

EPA, 1993. Implementation Paper for the New Paradigm. U.S. EPA Memorandum, 1993.

EPA, 1994. Report on the Workshop on Cancer Risk Assessment Guideline Issues, Risk Assessment Forum, U.S. EPA, Washington, DC, 1994.

ICH, 1993. International Conference on Harmonization (ICH) of Technical Requirements for the Registration of Pharmaceuticals for Human Use. Carcinogenicity: Guidance for Dose Selection for Carcinogenicity Studies of Therapeutics. Draft consensus text, ICH-2, Orlando, FL, 1993.

IPCS, 1990. Principles for the Toxicological Assessment of Pesticide Residues in Food. Environmental Health Criteria 104, WHO, Geneva, 1990.

OECD, 1987. Organization for Economic Cooperation and Development (OECD) Guidelines for Testing of Chemicals, "Carcinogenicity Studies", Guideline 459, 1987.

OECD, 1994. Comparison of Ecological Hazard/Risk Assessment Schemes: A Summary Document for the OECD Workshop on Environmental Hazard/Risk Assessment, 24-27 May, 1994

Ray, 1994. Ray, J.S.; Harbison, M.L.; McClain, R.M.; Goodman, J.I.; Molecular Carcinogenesis, 9: 155 - 166, 1994.

U.K., 1991. Guidelines for the Evaluation of Chemicals for Carcinogenicity. Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment, U.K. Department of Health, London, 1991.

U.S. National Research Council, 1993. National Research Council: Risk Assessment in the Federal Government: Managing the Process. Washington, DC: National Academy Press, 1983, 17-83.

Phytotoxic Activity of Peroxidizing Herbicides against Three Plant Cell Cultures, *Scenedesmus acutus, Marchantia polymorpha* and *Nicotiana glutinosa*

Hitoshi Kohno, Kou Shouda, Hiroyuki Watanabe[1)], Peter Böger[2)] and Ko Wakabayashi

Graduate School of Agricultural Science, Tamagawa University, Machida-shi, Tokyo 194, Japan

1) Yokohama Research Center, Mitsubishi Chemical Corporation, Yokohama-shi, Kanagawa-ken 227, Japan

2) Lehrstuhl für Physiologie und Biochemie der Pflanzen, Universität Konstanz, D-78434, Germany

Abstract. Phytotoxic effects of peroxidizing herbicides, e.g. oxyfluorfen, on chlorophyll content, protoporphyrin-IX accumulation and short-chain hydrocarbon formation were measured with *Scenedesmus acutus, Marchantia polymorpha* and *Nicotiana glutinosa.* The peroxidizing parameters were conveniently determined using cells of three plant species. Sensitivities of the peroxidizing herbicides to the three systems are described.

Key words: Peroxidizing herbicides, plant cell cultures, phytotoxic activity

INTRODUCTION

Plant tissue cultures are often used to study the mode of action of herbicides, because they exhibit several advantage like handling, growth or reproducibility.

However, photosynthetic activity of plant tissue cultures is considerably lower compared with that of the intact plants, because they are generally heterotrophically grown supplying sugar as carbon source. Therefore, there remain doubts whether the influence of the herbicides targeting photosynthesis accurately reflect those of intact plants. We believe that plant cells are good materials and methods in many cases. Here we report the use of plant tissue cultures of habituated tobacco cells and liverwort cells to determine herbicidal effects caused by peroxidizing herbicides, comparing them with phytotoxic data obtained from the autotrophic green microalgae, *Scenedesmus acutus.*

MATERIALS AND METHODS

1) Chemicals

Oxyfluorfen, 2-chloro-4-trifluoromethylphenyl 3-ethoxy-4-nitrophenyl ether, was prepared by treating 1,3-bis-(2-chloro-4-trifluoromethylphenoxy)-4-nitrobenzene, synthesized from resocinol, with ethanolic KOH (1).

Chlorophthalim, *N*-(4-chlorophenyl)-3,4,5,6-tetrahydrophthalimide, was prepared by the condensation reaction of 3,4,5,6-tetrahydrophthalic anhydride and 4-chloroaniline, according to own method given elsewhere (2).

Chemicals, analytical grade, for cell cultivation were purchased from Wako Chemical Corp.,Tokyo, Japan and fine chemicals including authentic protoporphyrin-IX (Proto-IX) and buffer from Sigma, München, Germany.

2) Cultivation of plant cells

HNG (habituated *Nicotiana glutinosa*) cells were grown on agar medium (AΣM80T) aseptically for 15 to 20 days at 25°C in the light of 6,000 lux as described (3).

Liverwort (*Marchantia polymorpha*) cells were grown in liquid medium as reported in ref. (4), on a rotary shaker at 150 rpm at 25°C in the light of 3,000 lux.

Microalgae (*Scenedesmus acutus*) cells were grown autotrophically in liquid culture medium at 22°C under gassing with 4% (V / V) of CO_2 / air in the light (approx. 6,000 lux) (5).

3) Phytotoxic assays

[*Experiments using HNG*]

Herbicides dissolved in methanol were added to 0.1g of HNG cells placed into gas-tight 10-ml vials suspended in 2 ml of liquid culture medium (AΣM80T medium except for agar). A two ml cell suspension was shaken at 25°C in the light (10,000 lux). After a 48-hr incubation, cell growth, chlorophyll content and short-chain hydrocarbon (ethane, ethylene and propane) formation were determined according to the methods given elsewhere(3). Proto-IX accumulation was determined during a 10-hr incubation with peroxidizing herbicides, 10^{-5} M.

[*Experiments using liverwort*]

Herbicides were applied to a 6-day old liverwort cell suspension (with a density of 10 µl packed cell volume / ml of cell suspension). Experiments were performed in gas-tight 10-ml vials. A two ml cell suspension was shaken at 25°C in the light (10,000 lux). After a 3-day incubation, cell growth, chlorophyll content and ethane formation were determined. Proto-IX accumulation was measured after a 12-hr incubation with oxyfluorfen, 10^{-5} M.

[*Experiments using Scenedesmus*]

Herbicides were applied to a 24-hr old algae cell suspension (with a density of 2 µl pcv / ml of cell suspension). Experiments were performed in gas-tight 9-ml vials. A two ml of algae suspension containing 5 mM of $NaHCO_3$ was shaken in a Warburg apparatus for 16 hr at 22°C in the light (17,000 lux).

After incubation, cell growth, chlorophyll content and short-chain hydrocarbon (mostly ethane) formation were determined according to the method given elsewhere (5). Proto-IX accumulation was determined during a 20-hr incubation with peroxidizing herbicides, 10^{-5} M.

4) Determination of peroxidizing activity

The pI_{50}-values of herbicides against growth, chlorophyll content and short-chain hydrocarbon formation were determined from dose-response relationship by means of Probit analysis (6).

RESULTS AND DISCUSSION

1) Phytotoxic parameters

[*HNG cells*] Accumulation of protoporphyrin-IX in the presence of oxyfluorfen was observed in HNG cells (Fig.1). The Proto-IX contents in HNG cells increased within 7 hrs, thenceforth Proto-IX decreased. Control HNG cells showed a very low level. This result indicates that protoporphyrinogen-IX oxidase catalysing chlorophyll biosynthesis was inhibited by peroxidizing herbicides.

Growth inhibition, chlorophyll decrease and short-chain hydrocarbon formation in HNG cells were also observed in the presence of peroxidizing herbicides after 48-hr incubation (Table 1). The short-chain hydrocarbon formation in HNG cells treated by the herbicides apparently is due to lipid peroxidation, following chlorophyll degradation and growth inhibition. The chlorophyll decrease, short-chain hydrocarbon formation and Proto-IX accumulation were also alleviated by the simultaneous addition of diuron. This result indicates that peroxidizing effects of the herbicides are somewhat related to photosynthesis (7).

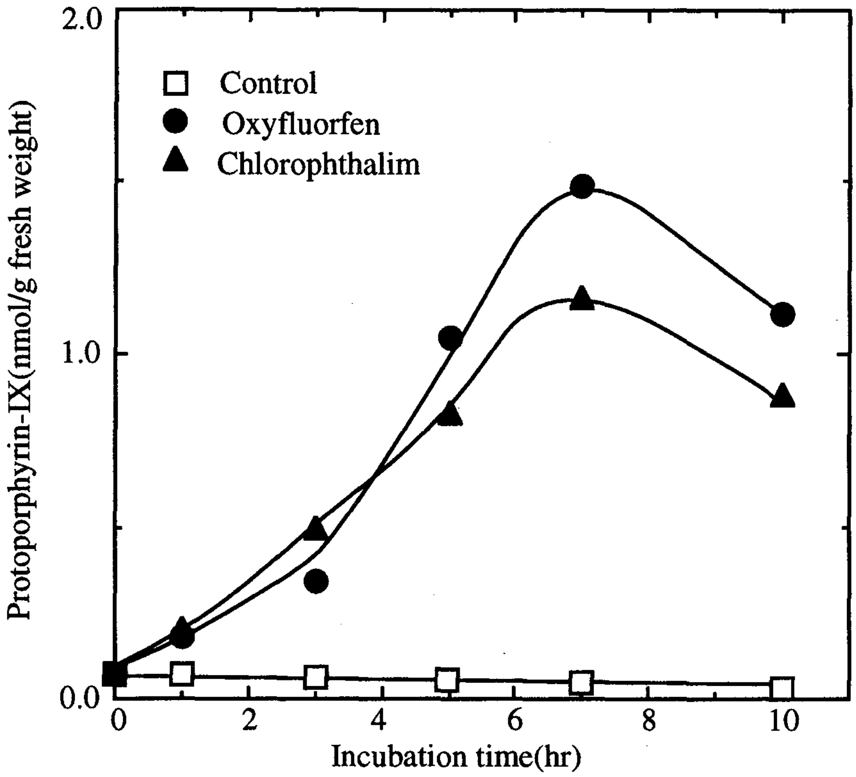


Fig.1 Time-course accumulation of protoporphyrin-IX in the presence of chlorophthalim and oxyfluorfen (10^{-5}M) in HNG (habituated *Nicotiana glutinosa*) cells

Table 1 Effects of diuron in the peroxidizing effects by peroxidizing herbicides in HNG (habituated *Nicotiana glutinosa*) cells after a 48-hr incubation

Culture condition	Growth (mg F.W.)	Chlorophyll content (μg/g F.W.)	Short-chain hydrocarbon formation (nmol/ g F.W.)	Proto-IX accumulation* (nmol/g F.W.)
Control	81.8	39.3	1.27	-
(+)Oxyfluorfen (10^{-6}M)	22.8	3.5	6.61	1.49
(+)Oxyfluorfen (+)Diuron (10^{-5}M)	78.0	36.4	1.26	0.71

* Proto-IX accumulation after a 7-hr incubation with peroxidizing herbicides, 10^{-5}M, F.W.= fresh weight.

Although the responses to peroxidizing herbicides of HNG cells were slower than those of *Scenedesmus* cells, HNG cells showed the same effects to peroxidizing herbicides, as was documented and explained in detail with *Scenedesmus* cells (8).

[*Liverwort cells*] Accumulation of Proto-IX in the presence of oxyfluorfen occurred in liverwort cells (Fig.2) as observed with HNG cells. Proto-IX in the liverwort cells slightly increased with a lapse of 7 hrs, thence the Proto-IX drastically increased and accumulated to a maximum after an 11-hr incubation. After that time, Proto-IX content in the cells decreased.

Growth, chlorophyll decrease and short-chain hydrocarbon formation in liverwort cells were also investigated in the presence of herbicides after a 3-day incubation (Table 2).

Although,in liverwort cells, these responses to peroxidizing herbicides as mentioned above were slower than those of HNG cells, liverwort cells showed the same response to peroxidizing herbicides as was observed with HNG cells and *Scenedesmus* cells. The diuron effect is not very much pronounced in contrast to HNG cells and autotrophic *Scenedesmus* (Table 2). It should be noted that we can detect a new tetrapyrrole (590FP) of Proto-IX when cultivating liverwort cells in the presence of peroxidizing herbicides (4). This tetrapyrrole is considered as the trigger of peroxidizing process (9).

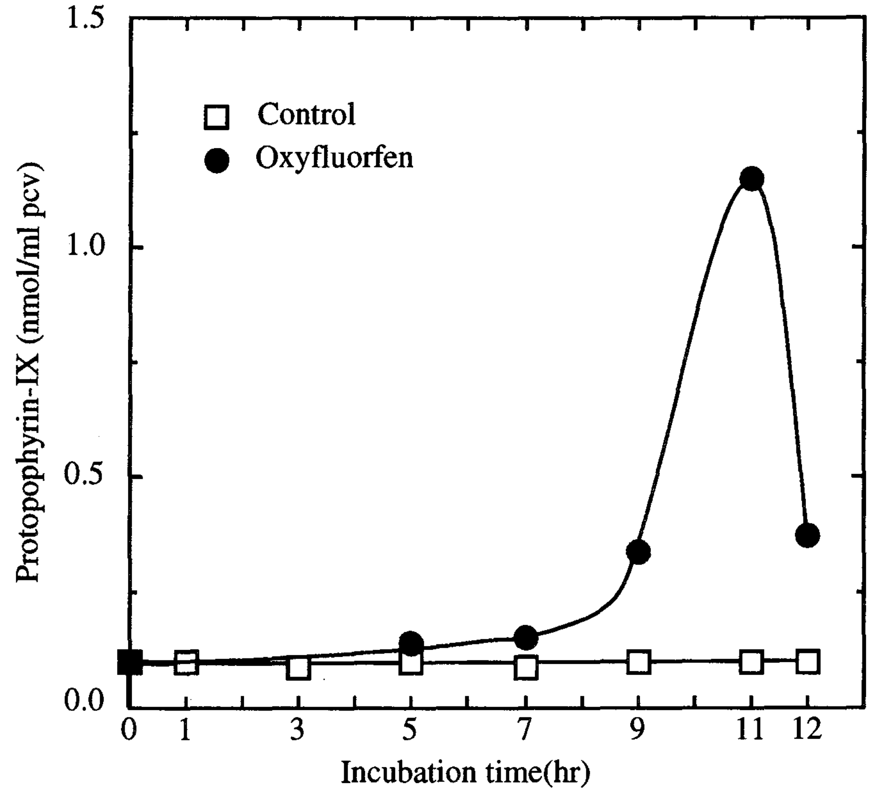


Fig.2 Time-course accumulation of protoporphyrin-IX in the presence of oxyfluorfen (10^{-5}M) in liverwort (*Marchantia polymorpha*) cells

Table 2 Effects of diuron in the peroxidizing effects in liverwort (*Marchantia polymorpha*) cells after a 72-hr incubation

Culture condition	Growth (μl pcv*/ml)	Chlorophyll content (μg/ml pcv*)	Short-chain hydrocarbon formation (*n*mol/ml pcv*)
Control	17.3	590.2	0.49
(+)Oxyfluorfen (10^{-5}M)	11.3	121.2	12.0
(+)Oxyfluorfen (+)Diuron (10^{-5}M)	10.5	102.5	n.d.**

* pcv= packed cell volume, ** n.d.= not determined.

[*Scenedesmus cells*] It has already reported that all peroxidizing phytotoxic parameters such as growth inhibition, chlorophyll decrease, short-chain hydrocarbon and Proto-IX accumulation are conveniently detected using green microalgae, *Scenedesmus acutus* (8). The assay with *Scenedesmus* can be done within a 16-hr treatment.

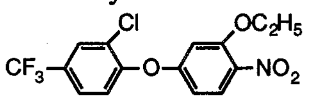
It is also known that diuron counteracts the peroxidizing effects in autotrophic *Scenedesmus* cells. In the dark-incubated heterotrophic cultures, no peroxidative ethane formation is detected. No inhibition by peroxidizing herbicides is found on photosynthesis and respiration at concentrations exceeding the pI_{50}-values for growth inhibition (8). These findings suggest that the peroxidizing herbicides induce radical reactions by affecting crucial enzymes and metabolic pathways including chlorophyll formation steps. Generation of activated oxygen, e.g. $^1O_2$ or hydroxyl radicals, which is mediated by Proto-IX and possibly by photosynthetic electron transport in the light. The light-dependent action of peroxidizing herbicides (10) is now discussed on this principle(11).

2) Comparison of phytotoxic data obtained from three types of cell cultures

Phytotoxic data of peroxidizing herbicides are assayed with HNG cells, liverwort cells and *Scenedesmus* cells (Table 3).

The pI_{50}-values indicating phytotoxic sensitivity to peroxidizing herbicide differed among three cell cultures. The strong peroxidizing herbicide, oxyfluorfen, confirmed already via *Scenedesmus* assay system (pI_{50} (Growth) 8.00; pI_{50} (Chlorophyll) 8.15; pI_{50} (Short-chain hydrocarbon) 7.00) also showed strong phytotoxic data (pI_{50} (Growth) 6.61; pI_{50} (Chlorophyll) 6.88; pI_{50} (Short-chain hydrocarbon) 6.69). The peroxidizing phytotoxity in HNG cell cultures, however, (pI_{50} (Growth) 6.55; pI_{50} (Chlorophyll) 6.56; pI_{50} (Short-chain hydrocarbon) 6.32) obtained from liverwort cell cultures are lower compared with these phytotoxic data. The response of three cell cultures to the peroxidizing herbicide is rather similar. Speediness and extent of the phytotoxic response is different. This fact may depend on difference in chlorophyll productivity or uptake of herbicides by the three plant cell cultures, or on endogenous radical-quenching systems.

Table 3 Phytotoxic activities of oxyfluorfen against tobacco cells, liverwort cells and *Scenedesmus* cells

		pI_{50}		
Compound	Plant species	Growth	Chlorophyll	Short-chain hydrocarbon
Oxyfluorfen	HNG[1)]	6.61	6.88	6.69
	LW[2)]	6.55	6.56	6.32
	Sce[3)]	8.00	8.15	7.00

1) HNG : habituated tobacco, 2) LW : liverwort, 3) Sce : *Scenedesmus acutus.*

Handling of HNG cells and liverwort cells for culture and phytotoxic assays of the herbicides is rather convenient. Thus the assay system using the HNG cells and the liverwort cells provides a reliable method for screening of peroxidizing herbicides as well as using *Scenedesmus*. The investigator may choose any one of the three cell cultures, whichever one can be handle best in his laboratory. Using the three cultures of this paper, we can also obtain resistant mutants against peroxidizing herbicides by selection, as was already achieved with *Scenedesmus* yielding an oxyfluorfen-resistant mutant (12).

ACKNOWLEDGMENTS

The authors are grateful to Dr. T. Tanaka and Mr. M. Sumida of Suntory Limited for supplying liverwort cell cultures.

REFERENCES

1. Yih, R. H. & C. Swithenbank, 1975. *J. Agric. Food Chem.*, **23**: 592~593.
2. Ohta, H., S. Suzuki, H. Watanabe, T. Jikihara, K.Matsuya & K. Wakabayashi, 1976. *Agric. Biol. Chem.*, **40**: 745~751.
3. Kohno, H., N. Katsuyama, H. Watanabe, K. Wakabayashi & P. Böger, 1994. *Plant Tissue Culture Letters*, **11**: 49~54.
4. Iwata, S., N. Nakayama, S. Nakagawara, Y. Ohta, T. Tanaka, K. Wakabayashi & P. Böger, 1992. *Z. Naturforsch.*, **47c**: 394~399.
5. Ogino, C., T. Hoshi, T. Iida, S. Koura, H. Ogawa, H. Kohno, Y. Sato, M. Takai & K. Wakabayashi, 1993. *J. Pesticide Sci.*, **18**: 369~373.
6. Lambert, R., G. Sandmann & P. Böger, 1983. *Pestic. Biochem. Physiol.*, **19**: 309~320.
7. Nicolaus, B., G. Sandmann, H. Watanabe, K. Wakabayashi & P. Böger, 1989. *Pestic. Biochem. Physiol*, **35**: 192~201.
8. Watanabe, H., Y. Ohori, G. Sandmann, K. Wakabayashi & P. Böger, 1992. *Pestic. Biochem. Physiol.*, **42**: 99~109.
9. Iwata, S., M. Sumida, N. Nakayama, T. Tanaka, K. Wakabayashi & P. Böger, 1994. "Porphyric Pesticides: Chemistry, Toxicology and Pharmaceutical Applications," ed. by S. O. Duke & C. A. Rebeiz, ACS Symp. Series No. 559, ACS, Washington DC, pp 147~160.
10. Matsunaka, S., 1969. *J. Agric. Food Chem.*, **17**: 171~175.
11. Wakabayashi, K., G. Sandmann, H. Ohta & P. Böger, 1988. *J. Pesticide Sci.*, **13**: 461~471.
12. Watanabe, H., 1992, Dissertation of Tamagawa University.

ENZYMATIC CONVERSION OF THIADIAZOLIDINE-TYPE PEROXIDIZING HERBICIDES INTO MORE ACTIVE TRIAZOLIDINES

Yukiharu Sato, Tetsuji Iida, Satoshi Senoo, Beate Nicolaus*, Ko Wakabayashi and Peter Böger*
Graduate School of Agricultural Science, Tamagawa University, Machida-shi, Tokyo 194, Japan
* Lehrstuhl für Physiologie und Biochemie der Pflanzen, Universität Konstanz, D-78434 Konstanz, Germany

Abstract. 4-Aryl-1,2-tetramethylene-1,2,4-triazolidines and their isomers, 5-arylimino-3,4-tetramethylene-1,3,4-thiadiazolidines were synthesized, and the phytotoxic activities were assayed by determining light-induced ethane formation and protoporphyrin-IX formation in *Scenedesmus acutus*, and root growth inhibition in *Echinochloa utilis*. They showed peroxidative activities. Triazolidines were up to 500 fold more active than thiadiazolidines for inhibition of protoporphyrinogen oxidase isolated from etiolated maize (*Zea mays* var. Anjou) seedlings. Interestingly, some thiadiazolidines were enzymatically and irreversibly converted into triazolidines. The rate of conversion depended upon the arylimino moieties and the presence of a carbonyl or thiocarbonyl group on the thiadiazolidine ring. On the other hand triazolidines were never converted into their corresponding thiadiazolidines. The converting enzyme from maize was purified and determined to be a glutathione *S*-transferase isoform.

Key words: 4-Aryl-1,2-tetramethylene-1,2,4-triazolidines, 5-arylimino-3,4-tetramethylene-1,3,4-thiadiazolidines, isomerization, glutathione *S*-transferase

INTRODUCTION

Peroxidizing compounds cause their phytotoxic activity by inhibiting protoporphyrinogen oxidase (protox) leading to destruction of cell membranes and formation of short-chain hydrocarbons. Selectivity, however, is a problem with peroxidizing herbicides since our knowledge on protox inhibitor sensitivity or on chemical modification of peroxidizers in the plant cell is still meager. During our previous resarch to find the intrinsic structure for peroxidation among the cyclic imide peroxidizers, we found some *N*-aryl-3,4,5,6-tetrahydroisophthalimides and 5-arylimino-3,4-tetramethylene-1,3,4-thiadiazolidines which were converted into their corresponding isomers in the presence of sawa millet (*Echinochloa utilis*) seedlings. Thus the isomers converted expressed phytotoxic activities (1,3,5). We found that this isomerization was caused by an enzyme in the culture of sawa millet, corn (4) and equine glutathione *S*-transferase (GST) catalyzed the isomerization in the presence of SH compounds, especially with reduced glutathione (GSH). Recently, Shimizu *et al.* (1994) have briefly reported that 5-(4-chloro-2-fluoro-5-methoxycarbonylmethylthiophenylimino)-3,4-tetramethylene-1,3,4-thiadiazolidin-2-one is converted into its triazolidine isomer in the presence of the impure GST from velvetleaf (7). In this paper, we present data on enzymatic isomerization of 5-arylimino-3,4-tetramethylene-1,3,4-thiadiazolidines and preliminary results on identification of the enzyme (isomerase) from corn (*Zea mays* var. Anjou), which is essential to isomerize the thiadiazolidine compounds.

MATERIALS AND METHODS

1. Chemicals

5-Arylimino-3,4-tetramethylene-1,3,4-thiadiazolidin-2-ones (thiadiazolidin-ones, nos. **1**~ **4** in Table 1), 5-arylimino-3,4-tetramethylene-1,3,4-thiadiazolidine-2-thiones (thiadiazolidine-thiones, nos. **5**~**7** in Table 1), 4-aryl-1,2-tetramethylene-1,2,4-triazolidin-3-one-5-thiones (triazolidin-one-thiones) and 4-aryl-1,2-tetramethylene-1,2,4-triazolidine-3,5-dithiones (triazolidine-dithiones) were synthesized according to the previous procedures cited in the references 2,3 and 5. *N*-Ethoxycarbonylhexahydropyridazines, synthesized from hydrazine via 4 steps, were treated with aryl isothiocyanate to yield 1-arylthiocarbamoyl-2-ethoxycarbonylhexahydropyridazines (I). Hydrolysis of 1-arylthiocarbamoyl-2-ethoxycarbonylhexahydropyridazines with KOH-ethanol gave 1-arylthiocarbamoylhexahydropyridazines (II). Cyclization of pyridazines (II) with trichloromethyl chloroformate or thiophosgene gave 5-arylimino-3,4-tetramethylene-1,3,4-thiadiazolidin-2-ones or 5-arylimino-3,4-tetramethylene-1,3,4-thiadiazolidine-2-thiones, respectively. Pyridazines (I) were heated with sodium acetate to give 4-aryl-1,2-tetramethylene-1,2,4-triazolidin-3-one-5-thiones. Treatment of pyridazine (II) with carbon disulfide yielded 4-aryl-1,2-tetramethylene-1,2,4-triazolidine-3,5-dithiones.

2. Assay of thiadiazolidines-converting activity into triazolidines (isomerase activity)

For the assay of thiadiazolidine converting activity, fraction 2 of Mono Q anion-exchange column was used as enzyme sample (for details see ref.4). To a total volume of 200 μl of 0.05 M potassium phosphate, pH 6.8, 0.1 mM thiadiazolidine, 1 mM GSH and enzyme sample were added, and the reaction was carried out at 30°C for 30 min. The reaction was stopped by addition of EtOAc (400 μl) followed by a 1 min centrifugation for complete phases separation. Pooled EtOAc extract was dried under nitrogen, dissolved in 50 μl acetonitrile and subjected to HPLC analysis using Nucleosil column (5 μm, Macherey & Nagel) and acetonitrile/H_2O (3:2) as mobile phase (flow rate: 1 ml/min). The amount of thiadiazolidines and triazolidines was determined by comparison of the integrated areas of the eluted peaks with a calibration standard.

3. Investigation of the co-factor for thiadiazolidine-converting enzyme (2,6)

Reduced glutathion (GSH), dithiothreitol (DTT), *S*-methyl-L-cysteine and methionine were investigated for co-factor activity of the isomerization enzyme. Thiadiazolidin-one **1** and thiadiazolidine-thione **5** were used as substrates, equine GST (Sigma) was used for isomerization enzyme. Results are shown in Table 2.

RESULTS AND DISCUSSION

1. Isolation of the thiadiazolidine-converting enzyme from corn seedlings

The details of the purification steps will be published in reference 4. Corn seedlings (*Zea mays* var. Anjou) were grown in vermiculite for 6 days in darkness at 30°C. After homogenization and ammonium sulfate fractionation, the crude extract was purified by HPLC system including a Mono Q anion-exchange column and GSH-affinity columns. The result of the separation by Mono Q anion-exchange column eluted with a NaCl gradients was shown in Fig. 1. Two active peaks (fraction 1 and 2) were recognized in this chromatography. Isomerization activity of the fraction 2 was measured using thiadiazolidin-one **1** as a substrate. As shown in Fig. 2, thiadiazolidin-one **1** was isomerized very rapidly into the corresponding triazolidine. After boiling the reaction solution, the isomerization was not recognized, indicating that isomerization occurred by means of an enzyme. This finding agrees with our previous results obtained with *Echinochloa* seedlings (2,3,5,6).

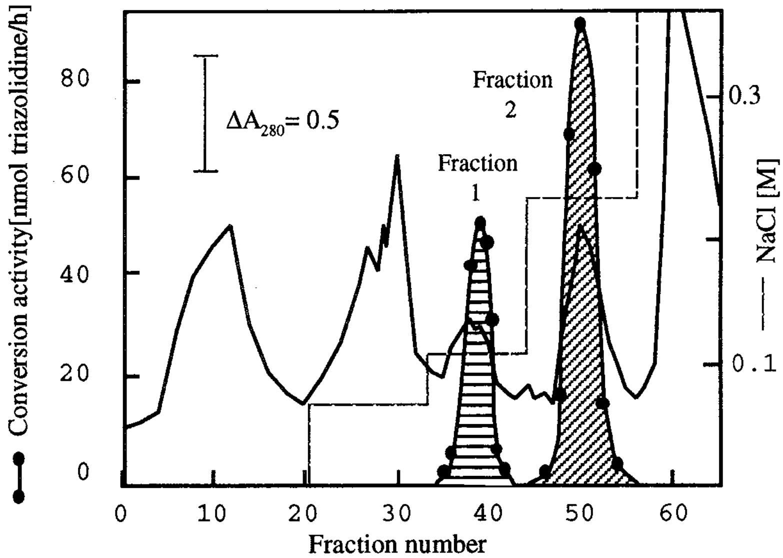


Fig. 1 Separation of two GST fractions on Mono Q
(see reference 4 for details)

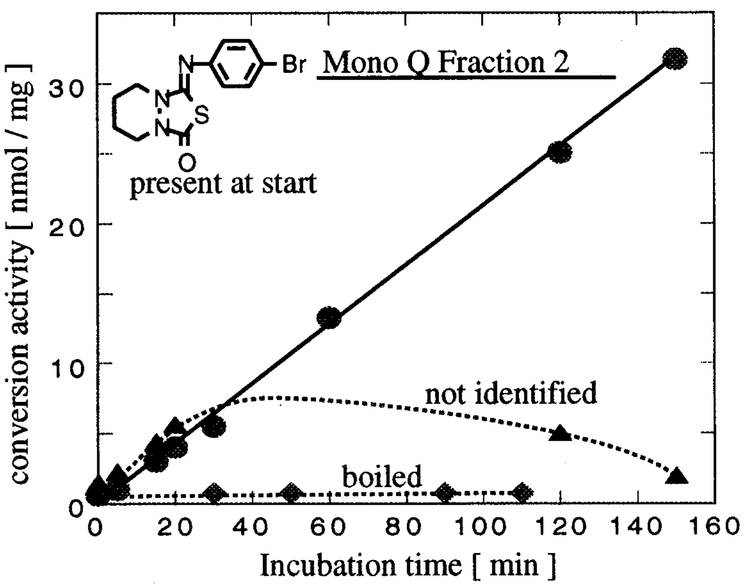
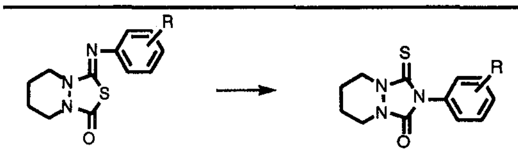
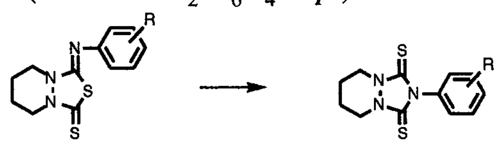


Fig.2 Isomerization of a thiadiazolidine by enzyme fraction 2 from corn

2. Conversion of thiadiazolidines into triazolidines

In the previous experiments, conversion of thiadiazolidin-ones into triazolidin-one-thiones was dependent on the 5-arylimino moiety and the thiadiazolidine-thiones were not isomerized into triazolidine-dithiones in the presence of *Echinochloa* seedlings and equine GST (2,3,5,6). Since it was presumed that only one enzyme or an enzyme family with similar reaction characteristics to GST was involved in the isomerization, we tried the conversion experiments using fraction 2 of Mono Q chromatography. The results are shown in Table 1. Thiadiazolidin-ones (nos. **1**,**2**,**3**) were converted into corresponding triazolidin-one-thiones rapidly, the order being nos. **1** and **2** > no. **3**. A very little conversion of thiadiazolidin-one no. **4** and thiadiazolidine-thiones (nos. **5**,**6**,**7**) were confirmed. These results are in good agreement with the previous experiments in which intact *Echinochloa* seedlings were used for conversion (2,3).

Table 1 Conversion of thiadiazolidin-ones and thiadiazolidine-thiones into triazolidines by isomerase isolated from corn seedlings.

(1) Compounds	(2)	(3) Protox I_{50} Thia / Tria [M]	Activity factor (4) between Thia / Tria
			
1 (R= 4-Br)	306*)	5.0 × 10^{-8} / 1.3 × 10^{-8}	385
2 (R= 4-Cl)	306	----------	----------
3 (R= 2-CH_3, 4-Cl)	194	3.1 × 10^{-6} / 2.0 × 10^{-7}	16
4 (R= 4-OCH_2-C_6H_4Cl-*p*)	3.2	6.9 × 10^{-6} / 1.3 × 10^{-8}	530
			
5 (R= 4-Br)	2.7	7.4 × 10^{-7} / 7.3 × 10^{-9}	101
6 (R= 4-Cl)	3.0	1.1 × 10^{-6} / 6.8 × 10^{-9}	162
7 (R= 4-OCH_2-C_6H_4Cl-*p*)	0.6	8.2 × 10^{-7} /1.2 × 10^{-8}	68.3

*) Specific activity in nmol converted per hr and mg protein

Table 1 shows that the conversion of thiadiazolidines into triazolidines by an isolated plant GST depends on the arly substituents and on the core structure of the thiadiazolidines (col. 2). The inhibition value (I_{50}) for protox is quite different for both types of compounds (col.3), yielding a ratio of I_{50} values up to 530 (col. 4).

3. Investigation of the co-factor for thiadiazolidine-converting enzyme

It is well known that GST exhibits its conjugating activity in the presence of GSH. Four candidates for co-factor, GSH, DTT, *S*-methyl-L-cysteine and L-methionine, were investigated with equine GST, and the result are shown in Table 2. Both thiadiazolidines did not convert into the corresponding triazolidines without any co-factors. Thiadiazolidin-one **1** converted into a corresponding triazolidine in the presence of GSH and DTT, but not with *S*-methyl-L-cysteine nor L-methionine. Thiadiazolidine-thione **5** did not convert into a corresponding triazolidine with these co-factors. These results show that equine GST needed SH compounds when it acted as thiadiazolidine-converting enzyme.

From our experiments up to this time, we conclude as follows:

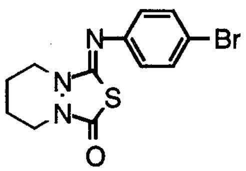
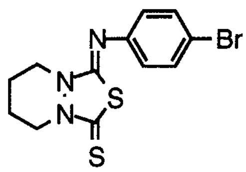
(1) Thiadiazolidin-ones are isomerized to corresponding triazolidin-one-thiones in the presence of *Echinochloa utilis* seedlings, *Scenedesmus acutus*, a homogenate of *Spinacia oleracea*, and an GST, obtained from corn (4). Presence of GST and SH compounds is required for isomerization.

(2) Thiadiazolidine-thiones barely convert into the corresponding triazolidine-dithiones under the same condition as mentioned above.

(3) No reverse isomerization of triazolidines into thiadiazolidines is observed under these conditions.

(4) The conversion of thiadiazolidines into triazolidines may have a bearing to herbicidal activity and selectivity. This selectivity was caused by the structural difference in thiadiazolidine structure, i.e. the difference between carbonyl and thiocarbonyl group, and the structural difference of the 5-arylimino moiety. Which kind of and how much activity of the GST, related to isomerization of thiadiazolidines, are still open for the discussion concerning herbicidal selectivity of thiadiazolidines.

Table 2. Co-factor requirement for equine GST

Compounds at start	Co-factor	Thiadiazolidine form	Triazolidine form
Thiadiazolidin-one			
	(–)[1]	98.4	1.6
	GSH	2.4	97.6
	DTT	3.8	96.2
	S-Methyl-L-cysteine	97.2	2.8
	Methionine	96.1	3.9
Thiadiazolidine-thione			
	(–)	96.0	n.d.[2]
	GSH	95.4	n.d.
	DTT	98.2	n.d.
	S-Methyl-L-cysteine	96.0	n.d.
	Methionine	94.9	n.d.

1) (–) : without co-factor
2) n.d. : not detected

REFERENCES

1. Hoshi T., K. Koizumi, Y. Sato and K. Wakabayashi. 1993, Hydrolysis and phytotoxic activity of *N*-aryl-3,4,5,6-tetrahydroisophthalimides. Biosci. Biotech. Biochem. 57: 1913-1915.
2. Iida T. 1995. Molecular design of peroxidizing herbicides; Intrinsic phytotoxic structure of *N*-bridgehead peroxidizing herbicides. Master thesis of Tamagawa University.
3. Iida T., S. Senoo, Y. Sato, B. Nicolaus, K. Wakabayashi and P. Böger. Isomerization and peroxidizing phytotoxicity of thiadiazolidine-thione compounds.

1995. Z. Naturforsch. 50c: in press.
4. Nicolaus B., Y. Sato, K. Wakabayashi and P. Böger. Isomerization of peroxidizing thiadiazolidine herbicides is catalyzed by glutathione *S*-transferase. Weed Sci., submitted.(1995)
5. Sato Y., T. Hoshi, T. Iida, C. Ogino, B. Nicolaus, K. Wakabayashi and P. Böger. 1994. Isomerization and peroxidizing phytotoxicity of thiadiazolidine herbicides. Z. Naturforsch. 49c: 49-56.
6. Sato Y., T. Hoshi, B. Nicolaus, K. Wakabayashi and P. Böger. 1994. Intrinsic phytotoxic structure of cyclic imide class of peroxidizing herbicides. Abstract paper, 8th Interna.Congress of Pesticide Chemistry, Washington D. C. p.749.
7. Shimizu T., N. Hashimoto, I. Nakayama, T. Nakao, H. Mizutani, T. Unai, M. Yamaguchi and H. Abe. 1994. Action mechanism of a new herbicide, KIH-9201 III. Abstract paper, 19th. Annu. Meeting Pesticide Science Society of Japan, Sapporo (Japan). p. 82

SELECTION OF HERBICIDE-TOLERANT SOYBEAN CELLS
AND MECHANISM OF TOLERANCE TO OXYFLUORFEN

T. Pornprom, H. Matsumoto, K. Usui and K. Ishizuka
Institute of Applied Biochemitry, University of Tsukuba

Abstract Soybean (*Glycine max* L. cv. Enrei) cells tolerant to oxyfluorfen, imazaquin, or fluazifop-P-butyl were tried to isolate and the mechanism of tolerance was investigated. By a stepwise selection with increasing concentration of the herbicides, the growth of imazaquin- and fluazifop-P-butyl-tolerant cells completely stopped when the cells were put into 10^{-6} M imazaquin or 10^{-4} M fluazifop-P-butyl. Only oxyfluorfen-tolerant cells which grew in a medium containing 10^{-6} M of the herbicide were successfully obtained. Oxyfluorfen concentration required to inhibit the growth of the tolerant cells by 50% was 5×10^{-6} M. This indicates that the selected nonchlorophyllous soybean cell line was 100-fold tolerant to oxyfluorfen than the non-selected (normal) cell. To clarify the tolerance mechanism absorption, metabolism, protoporphyrin IX (Proto IX) accumulation, protoporphyrinogen oxidase (Protox) inhibition, activities of the antioxidative system, and cross-tolerance to other herbicides were compared between the tolerant and normal cells. The results suggested that the tolerance is mainly due to less sensitivity of Protox and partially due to less absorption and high Protox activity. The oxyfluorfen-tolerant cells were found to have cross-tolerance to nitrofen, oxadiazon, and bifenox, although there was no cross-tolerance to bensulfuron-methyl.

Key words: oxyfluorfen, imazaquin, fluazifop-P-butyl, herbicide tolerance, soybean suspension cells, protoporphyrin IX, protoporphyrinogen oxidase, cross-tolerance

Introduction

Several types of herbicides including oxyfluorfen, imazaquin, and fluazifop-P-butyl, have been widely utilized to control major grasses and broadleaf weeds in soybean. Selection of cultivars tolerant to specific herbicides may offer new means to control weeds. To isolate a mutant which has tolerance to certain herbicide, *in vitro* selection technique has been employed because it can utilize large number of cells. Tolerant cell lines to several herbicides have been obtained by the technique. Recent reports introduced soybean cells tolerant to atrazine (Wrather and Freytag,1991) and clomazone (Norman *et al.*, 1990). However, there is still limited information on herbicide-tolerance in soybean cells. In the present study, the trials to select soybean cells tolerant to oxyfluorfen, imazaquin, and fluazifop-P-butyl and characteristics of the selected nonchlorophyllous soybean cell line is described.

Materials and Methods

Cell suspension culture

Soybean (*Glycine max* L. cv. Enrei) cell cultures induced from cotyledons were maintained in MS-medium supplemented with 2.0 mg/l 2,4-D and 20 g/l sucrose (pH 5.7), and incubated on a gyratory shaker at 110 rpm at 28°C under dim light. Subculturing was performed at every 10 days. A 10-fold increase of packed cell volume (PCV) during 10 days was repeatedly obtained. The oxyfluorfen-tolerant cells were maintained in the medium containing 10^{-7} M oxyfluorfen under continuous fluorescent light at about 50 $\mu Em^{-2}s^{-1}$.

Selection of soybean cells tolerant to herbicides

The growth response of soybean cells to the herbicides was determined by transferring 2 ml of cells into 100 ml of fresh medium containing different concentrations of the herbicides (10^{-9} to 10^{-6} M oxyfluorfen, 10^{-8} to 10^{-6} M imazaquin, and 10^{-7} to 10^{-4} M fluazifop-P-butyl). The survived cells were then transferred to a subsequent medium with the same or higher concentration of the herbicides. This process was repeated. To determine oxyfluorfen effect, suspension cultures were maintained under continuous fluorescent light at 50 $\mu Em^{-2}s^{-1}$.

Absorption and metabolism

Five days-old cells after subculturing (at the linear phase of the growth cycle) were treated with oxyfluorfen at the concentration of 5×10^{-8} or 5×10^{-6} M. Absorption and metabolism of oxyfluorfen were compared between the normal and tolerant cells according to the modified procedures of Lee *et al.* (1991).

Effect of light on the growth of oxyfluorfen-tolerant and normal soybean cells

Both cells were treated with 10^{-8} or 10^{-7} M oxyfluorfen and exposed to fluorescent white light (50 $\mu Em^{-2}s^{-1}$) or wrapped with an aluminum foil. To determine the effect of light intensity on the oxyfluorfen activity, the culture flasks were exposed to light at 0, 50, 100, 200 or 400 $\mu Em^{-2}s^{-1}$, respectively. Cytotoxic effects were evaluated by measuring PCV.

Protoporphyrin IX (Proto IX) determination

Both cells were treated with oxyfluorfen at the concentration of 5×10^{-8} or 5×10^{-6} M, and incubated in flasks which were placed under continuous fluorescent light at 50 $\mu Em^{-2}s^{-1}$ for 0.5, 1, 2, 4 or 8 hr. The same experiment was performed in darkness. The amount of oxyfluorfen-induced Proto IX accumulation was measured according to the modified procedures of Lee *et al.* (1992).

Protoporphyrinogen oxidase (Protox) assay

Protox activity was determined *in vitro* according to modified procedures of Sherman *et al.* (1991). Protein concentration was determined by using the method of Bradford (1976). The enzyme substrate, Protogen, was prepared according to Jacobs and Jacobs (1982).

Antioxidative system

Both cells were treated with 10^{-8}, 10^{-7} or 10^{-6} M rose bengal (a generator of $^1O_2$) and then exposed to fluorescent white light (50 $\mu Em^{-2}s^{-1}$) or wrapped with an aluminum foil. The relative growth of the cells at the various concentrations was estimated by measuring PCV over a cultured period of 10 days.

Determination of cross-tolerance

1. Growth of cells: The relative growth of oxyfluorfen-tolerant and normal soybean cells to other herbicides, was determined under different concentrations ranging from 10^{-10} to 10^{-5} M. The treated-cells were incubated on a gyratory shaker at 110 rpm under dim light (bensulfuron-methyl-treated) or continuous fluorescent light at 50 $\mu Em^{-2}s^{-1}$ (oxyfluorfen-, bifenox-, nitrofen-, and oxadiazon-treated). The effects of the herbicides were determined 10 days after treatment by the PCV.

2. Assay of Protox: Protox activity of the cells was determined by *in vitro* assay with various concentrations of the herbicides as described elsewhere (Pornprom *et al.*,1994).

Results and Discussion

Selection of soybean cells tolerant to these herbicides were attempted using suspension cultures induced from their cotyledons. The concentration required to inhibit the growth of normal cells by 50% were $5x10^{-8}$ M, $5x10^{-7}$ M, and 10^{-5} M for oxyfluorfen, imazaquin, and fluazifop-P-butyl, respectively. By a stepwise selection with increasing concentration of the herbicides, the cells tolerant to 10^{-7} M oxyfluorfen, $5x10^{-7}$ M imazaquin, and $5x10^{-5}$ M fluazifop-P-butyl were obtained. The growth of imazaquin- and fluazifop-P-butyl-tolerant cells, however, was completely stopped when the cells were transferred into 10^{-6} M imazaquin or 10^{-4} M fluazifop-P-butyl. Only oxyfluorfen-tolerant cells were grown in the medium containing 10^{-6} M of the herbicide. Oxyfluorfen concentration required to inhibit the growth of the tolerant cells by 50% was $5x10^{-6}$ M. This indicates that the tolerant cells were 100-fold more tolerant to oxyfluorfen than the normal cells. The acquired tolerance was stable for at least 6 months when the cells were retained in the medium without the herbicide.

The mechanism of tolerance of the selected cells to oxyfluorfen was investigated. The results are as follows.

Light was not required for the growth of both cells but was required for the activity of oxyfluorfen. No growth retardation of either cell line by oxyfluorfen was observed in darkness. Under light levels higher than 100 $\mu Em^{-2}s^{-1}$, the growth of the normal cells treated with 10^{-8} M oxyfluorfen completely stopped; however, no growth retardation of the tolerant cells was observed up to 10^{-7} M.

The tolerant cells absorbed less amount of oxyfluorfen than the normal cells. Metabolism of oxyfluorfen was not different between the two cell lines after 2 and 6 hr treatment. This suggests that lower absorption of oxyfluorfen in the tolerant cells may contribute to the tolerance but the tolerance is not metabolism-based.

Determination of Proto IX indicated that the normal cells accumulated much higher amount of Proto IX in the presence of $5x10^{-8}$ M oxyfluorfen. However, its accumulation in the tolerant cells treated with $5x10^{-8}$ M was considerably small. This suggests that the mechanisms for oxyfluorfen tolerance is related with reduced accumulation of the photodynamic porphyrin in the cells. Higher levels of Proto IX was also accumulated in treated cells in the light than in darkness. This indicates that light acts as an enhancer of the Proto IX accumulation.

The activity of Protox from the normal cell was more strongly inhibited by oxyfluorfen. The I_{50} values of Protox activity from the normal and tolerant cells were $5x10^{-10}$ and $6x10^{-9}$ M oxyfluorfen, respectively. The sensitivity of Protox differed about 12 times between the two cell lines. This differential Protox sensitivity is considered to cause differential levels of Proto IX accumulation. These data suggest that one of the tolerance mechanisms of the oxyfluorfen-tolerant cells is a decreasing sensitivity of Protox to oxyfluorfen. Higher activity of Protox in tolerant cells may also partially involved in the tolerance.

Rose bengal is known to singlet oxygen ($^1O_2$) generator. Rose bengal inhibited growth of both normal- and tolerant-cells under the light condition, however, growth inhibition was not observed under dark condition. The data suggests that rose bengal generated $^1O_2$ in the light and growth of the cell lines was inhibited by its photodynamic action. Therefore, it was considered that antioxidative system may not involved in the tolerance mechanism.

The relative growth of the both cells treated with other Protox inhibitors (bifenox, nitrofen, and oxadiazon) was determined to check their cross-tolerance. Sensitivities of the cells were compared by the determination of growth rates and the target enzyme inhibition. The growth of normal cells was severely inhibited by all Protox inhibitors whereas the tolerant cells was not. The oxyfluorfen-tolerant cells was found to have cross-tolerance to Protox inhibitors. However, the growth inhibition of the tolerant cells by bensulfuron-methyl indicated the lack of cross-tolerance to this herbicide which has different action mechanism. Protox enzyme from the tolerant cells was less sensitive to all inhibitors than that from the normal cells. The sensitivity of the enzyme preparations between the cells differed about 15-fold to oxyfluorfen, 30-fold to oxadiazon, 45-fold to bifenox, and 100-fold to nitrofen. There was a positive correlation between the tolerance ratio determined by growth rate and that at enzyme level. It may be concluded that the mechanism of oxyfluorfen tolerance in the selected nonchlorophyllous soybean cell line is principally due to a change in the sensitivity of the Protox enzyme to Protox-inhibiting herbicides.

Results of all above experiments are summarized in Table 1.

Table 1 Comparison of possible factors which may determine the tolerance of cells to oxyfluorfen.

Possible factors	Cells: Normal	Cells: Tolerant
1. Absorption	Greater	Less
2. Metabolism	Little	Little
3. Proto IX accumulation	Large	Small
4. Protox inhibition	Strong	Weak
- Protox (I_{50})	$5x10^{-10}$ M	$6x10^{-9}$ M
5. Antioxidative activity	Little	Little
6. Cross-tolerance		
- Protox inhibitors	Susceptible	Tolerant

Taken together, it may be concluded that the tolerance is mainly due to less sensitivity of Protox and partially due to less absorption and high Protox activity.

References

1. Wrather, A.J. and Freytag, A.H. 1991. Plant Cell Rep. 10, 44-47.
2. Norman, M.A., Liebl, R.A., and Widholm, J.M. 1990. Plant Physiol. 94, 704-709.
3. Lee, J.J., Matsumoto, H., and Ishizuka, K. 1992. Pestic. Biochem. Physiol. 44, 119-125.
4. Sherman, T.D., Duke, M.V., Clark, R.D., Sanders, E.F., Matsumoto, H., and Duke, S.O. 1991. Pestic. Biochem. Physiol. 40, 236-245.
5. Bradford, M.M. 1976. Anal. Biochem. 72,248-254.
6. Jacobs, J.M. and Jacobs, J.N. 1982. Enzyme 28, 206-219.
7. Pornprom, T., Matsumoto, H., Usui, K., and Ishizuka, K. 1994. Pestic. Biochem. Physiol. 50, 107-114.

KIH-9201, FOR POSTEMERGENCE BROADLEAF WEED CONTROL IN CORN(*Zea mays*) AND SOYBEANS(*Glycine max*)

S.Takahashi[1*], T.Miyazawa[1], K.Kawano[1], H.Sadohara[1], and M.Yamaguchi[2]
([1]Kumiai Chemical Industry Co., Ltd., [2]K-I Chemical Research Institute Co., Ltd.)

Abstract. KIH-9201(chemical name, methyl[[2-chloro-4-fluoro-5-[(5,6,7,8-tetrahydro-3-oxo-1H,3H-[1,3,4]thiadiazolo[3,4-a]pyridazin-1-ylidene)amino]phenyl]thio]acetate), a new low rate postemergence herbicide introduced by Kumiai Chemical Industry Co., Ltd., is used for controlling weeds in corn(*Zea mays*) and soybeans(*Glycine max*). KIH-9201 is an inhibitor of protoporphyrinogen oxidase. KIH-9201 provides excellent control of troublesome weeds, such as *Abutilon theophrasti Medic* , *Chenopodium album L.*, and *Amaranthus spp.* at 5-10 g a.i./ha. Corn and soybeans exhibit good tolerance to KIH-9201. Field and laboratory results to date indicate favorable environmental properties including a short half-life and no soil residual activity. KIH-9201 has been tested under the code number CGA-248757 by Ciba-Geigy Corporation in the United States.

Keywords: KIH-9201, CGA-248757, fluthiacet-methyl, soybeans, velvetleaf

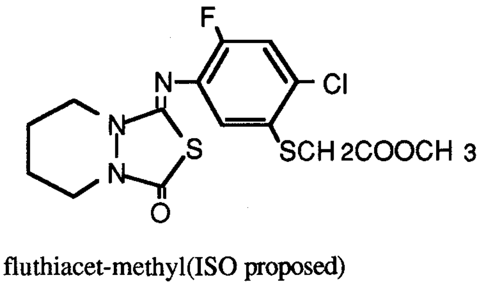
Introduction

Selective broad spectrum control of broadleaf weeds in corn and soybeans is needed for maximum yield potential, but most common herbicides do not control the complete weed spectrum. KIH-9201 is a potent new herbicide for corn and soybeans discovered by Kumiai Chemical Industry Co., Ltd.. It exhibits high activity on problem broadleaf weeds with good crop safety. KIH-9201 is currently being jointly developed in the U.S. by Kumiai and CIBA-GEIGY Corporation under the code number, CGA-248 757. This paper describes the chemical, physical and biological properties of KIH-9201.

Materials and Methods

Chemical and physical properties

Structure :



Common name	: fluthiacet-methyl(ISO proposed)
Chemical name (IUPAC)	: methyl[[2-chloro-4-fluoro-5-[(5,6,7,8-tetrahydro-3-oxo-1H,3H-[1,3,4]thiadiazolo[3,4-a]pyridazin-1-ylidene)amino]phenyl]thio]acetate)
Code number	: KIH-9201, CGA-248 757
Empirical formula	: $C_{15} H_{15} ClFN_3 O_3 S_2$
Molecular weight	: 403.88

Appearance	: white powder
Melting Point	: 107° C
Volatility	: extremely low
Solubility	: <1 mg/liter in water at 20℃

Toxicology of technical materials

Acute toxicity	:Oral LD50 rat		>5000 mg/kg
	Dermal LD50 rat		>2000 mg/kg
Acute fish toxicity	:Bluegill sunfish LD50		>0.13 mg/l
	Rainbow trout LD50		>0.072 mg/l
Irritation	:Skin, rabbit		non-irritant
	Eye, rabbit		slight irritant
Mutagenicity	:Non-mutagenic in Ames Test		
Teratogenicity	Non-teratogenic (Rat and rabbit)		
Subchronic toxicity	:No effect level,	Rat-	10 ppm (male)
			100 ppm (female)
		Mouse	10 ppm

Mode of action

KIH-9201 acts rapidly on foliage of sensitive species by inducing an accumulation of protoporphyrins, which enhances per oxidation of membrane lipids.(3,4) This leads to irreversible damage of membrane structure and cellular function in sensitive weeds. Light and oxygen are required for herbicidal activity. Symptoms include leaf necrosis which is often apparent within 24-48 hours.

Biological trials

Greenhouse trials with KIH-9201 were conducted in Japan using a 120 g a.i./ℓ EC formulation. Post-emergence applications were made in 250 ℓ/ha spray volume with a non ionic surfactant at 0.25% V/V. Test plants were in the one to five leaf stage at application. Visual evaluation of herbicidal effects were made 20-30 days after treatment as per cent activity. Pre-emergence soil applications were also evaluated.

Field experiments have been conducted since 1988 in the United States and Japan, as well as in other countries. Corn and soybeans trials contained two to four replicates, with a plot size of 10-30 m^2. Standard fertility and maintenance programs were used. KIH-9201 was applied in a spray volume of 200-400 ℓ/ha with a non ionic surfactant. Pre-emergence trials were also conducted. Standard commercial herbicides, such as acifluorfen(Blazer 2S, 24% a.i.), bentazon(Basagran 4S, 48% a.i.), chlorimuron(Classic 25DG, 25% a.i.), Imazethapyr(Pursuit 2E, 24% a.i.), thifensulfuron(Pinnacle 25DF, 25% a.i.), were included at their recommended rates and additives for comparison. Herbicidal activity and crop phytotoxicity were assessed visually at various intervals after treatment using a 0-100 per cent scale on crops and weeds.

Results and Discussion

Greenhouse Trials

Excellent control of many weed species was obtained from rates of 2.5-10 g a.i./ha. Table 1 shows the activity on nine weeds in greenhouse trials. Soybeans in the first to third trifoliate leaf stage and corn in the two to five leaf stage exhibited excellent tolerance to KIH-9201 at these rates.

TABLE 1. KIH-9201 post-emergence herbicidal activity and crop tolerance in greenhouse trials.

	% Activity		
Plant Species	10	5	2.5 (g a.i./ha)
velvetleaf (*Abutilon theophrasti*)	100	100	100
redroot pigweed (*Amaranthus retroflexus*)	100	100	100
lambsquarters(*Chenopodium album*)	100	100	90
Ivyleaf morningglory(*Ipomoea hederacea*)	96	85	63
tomentose knotgrass(*Polygonum lapathifolium*)	65	35	16
common purslane(*Portulaca oleracea*)	78	53	22
hemp sesbania(*Sesbania exaltata*)	93	90	78
common cocklebur(*Xanthium strumarium*)	100	100	92
Corn	4	0	0
Soybeans	2	0	0

Other greenhouse results show slender amaranth(*Amaranthus viridis*), *jimsonweed*(*Datura stramonium*), black nightshade(*Solanum nigrum*), prickly sida(*Sida spinosa*) and common dayflower(*Commelina communis*) to be susceptible to 10 g a.i./ha. Species tolerant to this rate include sicklepod(*Cassia tora*), common blackjack(*Bidens pilosa*), common chickweed(*Stellaria media*), green foxtail(*Setaria viridis*), large crabgrass(*Digitaria ciliaris*), common barnyardgrass(*Echinochloa crus-galli*) and johnsongrass(*Sorghum halepense*). At higher application rates, crop foliage present at application was burned, but new growth was not affected.

Field Trials in USA

KIH-9201 applied post-emergence in Corn and soybeans at 5-10 g a.i./ha showed selective control of problem broadleaf weeds, such as velvetleaf, redroot pigweed and lambsquarters (Table 2).

Table 2. Average per cent activity of KIH-9201 at 5 or 10 g a.i./ha on Corn, soybeans and broadleaf weeds (1 evaluation/trial taken 14-35 DAA).

	% Activity (No. of trials)			
Plant Species	5 g a.i./ha		10 g a.i./ha	
Corn	1.4	(31)	3.6	(20)
Soybeans	6.1	(71)	8.6	(69)
velvetleaf	95	(38)	99	(31)
lambsquarters	79	(40)	88	(39)
redroot pigweed	66	(30)	79	(21)

KIH-9201 exhibits superior post-emergence application timing flexibility on velvetleaf and lambsquarters, when applied at 5-10 g a.i./ha, as compared to several standards (Table 3). At the lowest rate tested, KIH-9201 gave complete control of velvetleaf, regardless of growth stage. On lambsquarters, KIH-9201 performed better than most standards. Corn and soybean selectivity was not affected by application timing.

Table 3. Influence of stage of weed growth on performance of KIH-9201 gave compared to commercial standards (3-12 weeks after application).

Product	Rate (g a.i./ha)	Stages(cm)	Average % Control (No. of trials) velvetleaf(5) 2-15	10-51	lambsquarters (3) 1-5	2-15
KIH-9201	5		100	100	85	89
KIH-9201	10		100	100	97	97
acifluorfen	560		54	66	79	79
chlorimuron	13		86	82	37	69
imazethapyr	70		86	88	63	58
bentazon	1120		92	87	87	90
thifensulfuron	4.4		90	91	90	96

Pre-emergence applications resulted in almost no effect on all crop and weed species tested, even from application rates up to 120 g a.i./ha. Based on this and limited recropping data, no limitations in rotational flexibility are expected.

The rapid activity of KIH-9201 enhances the early performance activity when used in combinations. Table 4 shows that this effect is still manifest at 21-42 days after application where tank-mixes of KIH-9201 with commercial standards improves activity on the key weed species controlled by KIH-9201 alone (e.g. velvetleaf and lambsquarters) without negatively affecting activity on weed species well controlled by the standards (e.g. common cocklebur).

Table 4. Efficacy of KIH-9201 at 5 g a.i./ha alone and in tank-mixtures (t-mix*) with commercial standards in soybeans (two to four trials per species; evaluations 21-42 DAA)

Product	Rate (g a.i./ha)	Average % Control Across Trials velvetleaf(2) alone	t-mix*	lambsquarters (3) alone	t-mix*	common cocklebur (4) alone	t-mix*
KIH-9201	5	100	-	84	-	38	-
acifluorfen	840	94	100	84	93	68	65
bentazon	1120	99	100	71	80	82	92
chlorimuron	13	82	100	26	67	87	86
imazethapyr	70	85	99	50	87	86	93
thifensulfuron	4	79	100	74	94	65	65

These results show the utility of KIH-9201 to broaden the spectrum of various standards to ensure control of problem species such as velvetleaf, lambsquarters and possibly others. Further work is underway to confirm the enhanced control of these and other species in Corn and soybeans with the appropriate standards.

Conclusions

1. Greenhouse results obtained with KIH-9201 demonstrated post-emergence corn and soybean selectivity and herbicidal activity on certain problem broadleaf weeds when applied in the 5-10 g a.i./ha range.

2. Field results confirmed the post-emergence corn and soybean selectivity of KIH-9201 at 5-10 g a.i./ha and efficacy on important broadleaf species such as velvetleaf, lambsquarters and redroot pigweed.

3. The high level of activity allows post-emergence applications with appropriate additives over a wide range of growth stages of velvetleaf and lambsquarters, while maintaining crop selectivity.

4. KIH-9201 can be used in combination with other products to ensure control of such problem species as velvetleaf, lambsquarters and others for broad spectrum control.

5. Initial trials show no problems with rotational flexibility because of little pre-emergence activity, even from excessive rates.

6. Trials underway show KIH-9201 to have a favorable toxicological and environmental profile.

Acknowledgements: The authors thank the colleagues in Kumiai Chemical Company, Ihara Chemical Company, K-I Chemical Research Company, and CIBA-GEIGY, who contributed to the development of KIH-9201, for their cooperation.

References

1. Kobayashi, K., T.Miyazawa, M.Yamaguchi, S.Shigematsu, 1994, Characterization of a New Compound, KIH-9201, as a New Post-Emergence Herbicide and its Application in the U.S.A., Weed Research, Japan 39 Supplement I ,14-15

2. Miyazawa, T., K.Kawano, S.Shigematsu, M.Yamaguchi, K.Matsunari, P.Porpiglia, K.G.Gutbrod, 1993, KIH-9201, A New Low-Rate Post-Emergence Herbicide for Maize*(Zea mays)*, and Soybeans*(Glycine max)*, Brighton Crop Protection Conference - Weeds -, 23 - 28.

3. Shimizu,T., N.Hashimoto, I.Nakayama, T.Nakao, K.Ikegami, M.Yamaguchi, H.Abe, 1994, Action Mechanism of a New Herbicide, KIH-9201, I. Inhibition of Chlorophyll Biosynthesis, Accumulation of Porphyrins and Electrolyte Leakage Caused by KIH-9201, Weed Research, Japan 39 Supplement I ,154-155

4. Shimizu,T, N.Hashimoto., I.Nakayama, T.Nakao, H.Mizutani, T.Unai, M.Yamaguchi, H.Abe, 1994, Action Mechanism of a New Herbicide, KIH-9201, II. Isomerization of KIH-9201 by glutathion S-transferase and Inhibition of Protoporphyrinogen oxidase by KIH-9201 and Isomer, Weed Research, Japan 39 Supplement I ,156-157

6. Yamaguchi,M., K.Matsunari, T.Miyazawa, S.Shigematsu, 1994, KIH-9201,Studies on A New Low-Rate Post-Emergence Herbicide for Maize*(Zea mays)*, and Soybeans*(Glycine max)*, Synthesis and Biological activity, Pesticide Science Society, Japan, 60

Calculating Chlorsulfuron Concentration in Plants: an Approach for Detecting the Mechanism of Herbicide Sensitivity

F. Dastgheib and R.J. Field

Department of Plant Science, P.O.Box 84, Lincoln University, Canterbury, New Zealand

Abstract. Two wheat cultivars with different sensitivity to chlorsulfuron were used in an approach to demonstrate the fate of the herbicide in the plant following a foliar application. An analysis of chlorsulfuron concentration in the tissues of wheat cultivars Kotare (tolerant) and Rongotea (sensitive) showed that retention, uptake, translocation and distribution of the herbicide did not account for differences in sensitivity. The concentration of un-metabolised chlorsulfuron in the young expanding tissues of Rongotea and Kotare were 15.6 and 1.2 ng/g dry weight, respectively, 48 h after application. The rate of metabolism of chlorsulfuron was different between the wheat cultivars tested and explained the difference in tolerance to the herbicide. Calculation of herbicide concentration in each plant compartment, for each event in the process following herbicide application is described.

Key words. cultivar sensitivity, herbicide selectivity, herbicide tolerance, sulfonylurea, wheat.

INTRODUCTION

Variations in the performance of a foliar-applied herbicide have been associated with differential spray deposit, uptake and translocation or metabolism within the plant (Hathway, 1986; Owen, 1989; Hess and Falk, 1990; Devine and Vanden Born, 1991). Variations in one or more of these events may cause changes at the target site in the concentration of the herbicide in toxic form. This may induce variations in biochemical responses leading to changes in plant growth and physiology. In order to investigate the main reason(s) for variations in the concentration at the target site, the amount of herbicides reaching different plant parts should be determined at each step.

Chlorsulfuron (Glean, 750 DF) is a highly active herbicide from the sulfonylurea group recommended for weed control in cereals at rates less than 20 g a.i./ha. Wheat (*Triticum aestivum* L.) cultivars showed differential tolerance to the application of chlorsulfuron (Dastgheib, Field and Namjou, 1994). Similar differences in sensitivity to chlorsulfuron amongst cultivars have been reported by various workers (Anderson, 1986; Wicks, Norquist and Schmidt, 1987; Bowran and Blacklow, 1987). However, the physiological reasons for such differences in chlorsulfuron activity have not been previously elucidated.

Very little published information is available to correlate sensitivity of different crop cultivars to chlorsulfuron, or other sulfonylurea herbicides, with their uptake, translocation or metabolism. Blacklow and Pheloung (1987) reported that detached leaves of sensitive wheat cultivars metabolised chlorsulfuron more slowly than tolerant cultivars. Matthews *et al.* (1990) found some evidence to correlate resistance to chlorsulfuron in an annual ryegrass (*Lolium rigidum* L.) biotype to its ability to oxidise the herbicide to a less active catabolite. Similarly, Harms et al. (1990) found that differential metabolism was the mechanism of tolerance of maize (*Zea mays* L.) inbred lines to the sulfonylurea herbicide primisulfuron.

The objective of the present study was to demonstrate an approach in identifying the mechanisms for differential sensitivity of wheat cultivars to foliar application of chlorsulfuron by calculation of the amount of herbicide reaching various plant parts during transfer to the target site. Thus retention of chlorsulfuron on the foliage, its uptake by the leaves, its translocation and distribution inside the plant and its rate of metabolism within the plant were compared in two wheat cultivars with different degrees of tolerance to chlorsulfuron.

MATERIALS AND METHODS

Cultivar tolerance pot experiment

Seeds of Kotare and Rongotea wheat were sown into 200-mm diameter black plastic (planter) bags containing 9 kg of Templeton silt loam soil. Pots were maintained outdoors and thinned to a final stand of five plants per pot. When plants had reached the three-leaf stage (ZGS 13), they received an application of chlorsulfuron at 0, 15, or 60 g a.i./ha. Chlorsulfuron was applied with a CO_2 pressurized sprayer which delivered 250 l of water/ha at 275 kPa. Citowett surfactant was added to the spray solution at a concentration of 0.25 ml/l. The experiment was a randomized complete block design replicated five times. Plants were harvested 43 days after spraying (DAS) and their shoot dry weights determined.

Cultivar tolerance field experiment

The experiment was carried out on a Wakanui silt loam soil at the Lincoln University research farm. Seeds of Kotare and Rongotea were drilled in 0.15-m rows at a population of 260 plants/m^2. Chlorsulfuron was applied at the same rate and at the same plant stage as described above. Weeds in all unsprayed control plots were removed by hand. The experiment was laid-out in a randomized complete block design with four replicates. At 21 DAS, plants from two 0.1 m^2 quadrats, placed at random, were cut to ground level for determination of shoot dry weight.

Retention of chlorsulfuron by foliage.

Seeds of wheat cultivars Kotare and Rongotea were sown in 700-ml volume plastic pots containing Templeton silt loam soil. These were kept outdoors alongside plants from cultivar tolerance pot experiment and thinned to two seedlings per pot. The experiment was a randomized complete block design with four replicates.

At the three-leaf stage plants were sprayed with a solution containing chlorsulfuron (15 g a.i./ha), Citowett (0.25 ml/l) and fluorescein dye (0.05 g/l) and retention of chlorsulfuron on the foliage was determined as described previously (Dastgheib *et al.,* 1994).

Uptake and translocation of ^{14}C-chlorsulfuron

Wheat seedlings from cultivars Kotare and Rongotea were grown individually in 350-ml volume plastic pots filled with Templeton silt loam soil and maintained in a controlled environment cabinet at 12 h daylength and day/ night temperature of 20/10 °C. The experiment was a randomized complete block design with four replicates.

Radiolabelled chlorsulfuron was applied at the three-leaf stage. Ten µl ^{14}C-chlorsulfuron formulated in Citowett solution (0.25 ml/l) was applied as 35-40 droplets with a micro-syringe to the adaxial surface of the lamina of leaf 2. The final concentration of radioactivity was 0.05 µCi in 10 µl. Uptake of ^{14}C-chlorsulfuron was measured 12 h and 48 h after application of the radiolabel as described previously (Dastgheib *et al.,* 1994). In addition, the distribution of radioactivity in different plant parts was determined.

Metabolism of chlorsulfuron

Plant culture and growing conditions were the same as described above. Experimental design was a randomized complete block with four replicates. Ten µl ^{14}C-chlorsulfuron, formulated as described above, was applied as 18-20 droplets to the adaxial laminar surface of each of leaf 2 and 3. Two plants were paired as one plot for analysis. Metabolism of chlorsulfuron was measured as described previously (Dastgheib *et al.,* 1994).

Chlorsulfuron concentration in young tissues following a foliar application

By considering data on retention, distribution and metabolism of chlorsulfuron, obtained from the experiments described above, it was possible to calculate the amount of un-metabolised chlorsulfuron reaching the young tissues following a foliar application of 15 g a.i./ha, using equation 1.

$$A = R * C * D_y * P / \text{dry weight} \qquad \text{(eq.1)}$$

where R is the retention of spray solution by plant foliage in μl/plant (Table 2), C is the concentration of chlorsulfuron in the spray solution (0.06 μg/μl), D_y is distribution of radioactivity in young plant tissues as proportion of applied dose (Table 2), P is the amount of parent chlorsulfuron as a proportion of the total (derived from Table 2) and A is the concentration of un-metabolised chlorsulfuron in young tissues in μg/g dry weight.

Statistical Analysis
All experiments were carried out at least twice and only the typical results are presented. All data were subject to analysis of variance. In the tolerance experiments means of sprayed plants were compared with that of the control using Dunnet's procedure. The Dunnet's statistic, designed as 'd' is presented with the means for each cultivar. Counts of radioactivity and percentage values were transformed using square root and arcsine transformation respectively, before analysis. Since the results were similar for the untransformed and transformed data only the former are presented.

RESULTS

Cultivar tolerance experiments
Data from both pot and field experiments showed the difference in sensitivity to chlorsulfuron between the two wheat cultivars tested (Table 1). Kotare showed no significant reduction in shoot dry weight up to 60 g a.i./ha chlorsulfuron while shoot dry weight of Rongotea was reduced even with the recommended field rate of 15 g a.i./ha.

Table 1. Effect of chlorsulfuron on shoot dry weight of wheat cultivars. Measurements were taken 43 days after spraying (DAS) in the pot experiment and 21 DAS in the field experiment.

Chlorsulfuron rate	Pot experiment		Field experiment	
(g a.i./ha)	Kotare	Rongotea	Kotare	Rongotea
0	1.16	0.94	0.44	0.47
15	0.98	0.68*	0.39	0.40*
60	0.85	0.46*	0.36	0.33*
d	**0.312**	**0.250**	**0.093**	**0.060**

* An asterisk indicates a significant reduction compared with the control at $p<0.05$.

Retention and radiotracer experiments
No differences were found between Kotare and Rongotea cultivars in herbicide retention, expressed either on a per plant or per unit dry weight basis (Table 2). At 48 h after application, uptake was low and similar in both Kotare and Rongotea. Moreover, translocation of ^{14}C-chlorsulfuron out of the treated area was similar in Kotare and Rongotea either expressed as a percentage of the applied dose or as a percentage of the total radioactivity recovered from plant (Table 2).

Distribution of radioactivity in various plant parts of wheat cultivars 48 h after application is shown in Table 3. In both cultivars, leaf 2 lamina (the treated area) contained significantly more radioactivity than any other plant part. Rongotea had slightly more radioactivity in its young tissues than Kotare.

Metabolism of ^{14}C-chlorsulfuron
Significant differences in metabolism of chlorsulfuron were found between wheat cultivars (Table 2). At 48 h after application, Kotare had metabolised more than 92% of the chlorsulfuron compared to 63% metabolism in Rongotea.

Table 2. Retention, uptake, translocation and distribution of ^{14}C-chlorsulfuron in two wheat cultivars. Retention was measured 30 minutes after application and all the other measurements were taken 48 h after application.

Event	Kotare	Rongotea	F test
Retention (µl plant^{-1})	10.8	11.3	ns
Retention (µl g^{-1} dry wt)	207.6	188.2	ns
Uptake (% applied)	14.4	16.7	ns
Translocation (% applied)	8.5	8.9	ns
Translocation (% recovered)	14.4	18.5	ns
Distribution in young tissues (% applied)	7.1	10.9	*
Metabolism (%)	92.2	63.0	*

* An asterisk indicates a significant difference at $p<0.05$.

Table 3. Distribution of radioactivity in various parts of wheat cultivars 48 h after application of ^{14}C-chlorsulfuron to leaf 2 lamina. Values are percentage of radioactivity recovered from the plant.

Cultivar	Leaf 1	Leaf 2 lamina	Leaf 2 sheath	Young tissue	Root
Kotare	0.68	85.64	2.37	7.08	4.23
Rongotea	0.57	81.51	2.27	10.94	4.27
sem	**0.107**	**1.745**	**0.431**	**0.921***	**0.576**

* An asterisk indicates a significant difference at $p<0.05$.

Fate of chlorsulfuron in the plant following a foliar application

Figure 1 shows the calculated values for the amount (ng/plant) or concentration (ng/g dry weight) of chlorsulfuron in the plant for Kotare and Rongotea cultivars following a foliar application at the recommended rate of 15 g a.i./ha. No differences were observed between the two cultivars in retention, uptake and translocation of chlorsulfuron, and the ratio of Rongotea : Kotare for the amount or concentration of chlorsulfuron did not exceed 1.3 for any of the specified compartments. Distribution of chlorsulfuron and metabolites to young tissues of Rongotea was 2.4 and 2.8 times greater than for Kotare, based on a per plant and per dry weight basis, respectively. Differential metabolism of chlorsulfuron by these cultivars greatly increased the difference between the cultivars in the concentration of the herbicide in meristematic tissues. Thus, 48 h after spraying, young tissues of Rongotea contained 15.6 ng/g dry weight of un-metabolised chlorsulfuron compared to only 1.2 ng/g dry weight for Kotare. This means that the concentration of chlorsulfuron in young tissues of Rongotea was 12.8 times as much as that of Kotare (Figure 1).

Figure 1: **Diagram showing the amount of chlorsulfuron at different events involved in herbicide application. Values are calculated for Kotare and Rongotea wheat 48 h after a foliar application of 15 g a.i./ha.**

ng/plant Rongotea : Kotare	EVENTS	ng/g dry weight Rongotea : Kotare
	RETENTION	
675 : 647 **(1.0)***	Chlorsulfuron deposited on foliage	**2551 : 2273** **(1.1)**
	↓ **UPTAKE**	
112 : 93 **(1.2)**	Chlorsulfuron taken into foliage	**423 : 327** **(1.3)**
	↓ **TRANSLOCATION**	
60 : 55 **(1.1)**	Chlorsulfuron moved to different parts	**227 : 193** **(1.2)**
	↓ **DISTRIBUTION**	
3.6 : 1.5 **(2.4)**	Chlorsulfuron and metabolites in young tissue	**42.2 : 15.3** **(2.8)**
	↓ **METABOLISM**	
1.33 : 0.12 **(11.1)**	Chlorsulfuron in young tissue	**15.6 : 1.22** **(12.8)**

* Values in brackets are the ratio of Rongotea : Kotare in the amounts of chlorsulfuron available at each event.

DISCUSSION

The results of this study demonstrate that some wheat cultivars have low levels of tolerance to chlorsulfuron. It is important to find explanations for differential sensitivity to chlorsulfuron between cultivars. In order for chlorsulfuron to affect plant growth, it must be retained, absorbed and translocated to the site of action in meristematic tissues at high enough concentrations to elicit a physiological effect that results in cell death.

Data in Table 2 and Figure 1 show that retention, uptake and translocation of chlorsulfuron were similar between the tolerant Kotare and the sensitive Rongotea. Relatively higher amount of total radioactive material reached the young tissues of Rongotea than those of Kotare. The diagram of chlorsulfuron concentrations in the plant in each compartment (Figure 1), demonstrates the contribution of individual events following a foliar application and facilitates their ranking. Based on the data provided, differential metabolism is the main reason for differences in sensitivity between Rongotea and Kotare. The small difference between cultivars in the distribution of chlorsulfuron, does not seem to account, by itself, for differential sensitivity between cultivars. It might however, contribute to greater sensitivity of a cultivar which has a low capacity to detoxify chlorsulfuron.

REFERENCES

1. Anderson, R.L. 1986. Metribuzin and chlorsulfuron effect on grain of treated winter wheat (*Tricium aestivum). Weed Science* 34: 734-737.
2. Blacklow, W.M., P. Pheloung. 1987. The field-exposure and metabolic reaction of wheat cultivars to chlorsulfuron. *Proceedings of the 8th Australian Weeds Conference.* Sydney, Australia: Weed Society of NSW, pp 399.
3. Bowran, D.G., W.M. Blacklow. 1987. Sensitivities of spring wheat cultivars to chlorsulfuron measured as inhibitions of leaf elongation rates and there were genotype x environment interaction. *Aust. J. Agr. Res.* 38: 253-262.
4. Dastgheib, F., R.J. Field, S. Namjou. 1994. The mechanism of differential response of wheat cultivars to chlorsulfuron. *Weed Research.* 34: 299-308.
5. Devine, M.D., W.H. Vanden Born. 1991. Absorption and transport in plants. P119-140 **in**: Grover, R., A.J. Cessna (eds). Environmental Chemistry of Herbicides. Vol. II. CRC Press, BOCa Raton, Florida.
6. Harms, C.T., A.L. Montoya, L.S. Privalle, R.W. Briggs. 1990. Genetic and biochemical characterization of corn inbred lines tolerant to the sulfonylurea herbicide primisulfuron. *Theoretical and Applied Genetics.* 80:353-358.
7. Hathway, D.E. 1986. Herbicide selectivity. *Biological Reviews* 61: 435-486.
8. Hess, D.F., R.H. Falk. 1990. Herbicide deposition on leaf surfaces. *Weed Sci.* 38: 280-288.
9. Matthews, J.M., J.A.M. Holtum, D.R. Liliegren, B. Furness, S.B. Powles. 1990. Cross resistance to herbicides in annual ryegrass (*Lolium rigidum*). I. Properties of the herbicide target enzymes acetyl-coenzyme A carboxylase and acetolactate synthase. *Plant Physiology* 94: 1180-1186.
10. Owen, W.J. 1989. Metabolism of herbicides - detoxification as a basis of selectivity. p 171-198 **in:** Dodge, A.D. (ed). Herbicides and Plant Metabolism. Society for Experimental Biology. Seminar series 38. Cambridge University Press, Cambridge.
11. Wicks, C.T., P.T. Norquist, J.W.A. Schmidt. 1987. Response of winter wheat (*Triticum aestivum*) to herbicides. *Weed Science* 35: 259-262.

ACTIVITY OF A SULFONYLUREA HERBICIDE AZIMSULFURON (DPX-A8947) IN COMBINATION WITH BENSULFURON METHYL

Shinichi Shirakura**, Kenji Ito**, Stephen K. Gee***, Aldos C. Barefoot*** and Hiroyasu Aizawa**

Abstract. Azimsulfuron (DPX-A8947) is one of sulfonylurea herbicides developed by E.I. du Pont de Nemours and Co. Inc. as a paddy rice herbicide. Results of greenhouse pot tests indicated that azimsulfuron at a rate as low as 6ga i./ ha affords excellent control of sedge and perennial weeds. Especially activity on Cyperus serotinus and Eleochalis kuroguwai was significantly higher than that of bensulfuron-methyl(BSM). Azimsulfuron afforded a comparable rice safety to that of BSM at 75ga i./ ha up to 12 g a.i./ha under the tested conditions. Ingreenhouse studies, we could see a clear advantage of mixing azimsulfuron with BSM. Addition of azimsulfuron significantly improved the activity of BSM on perennial sedges without increasing rice injury and reduced the total quantity of chemicals used. This combination controlled the tested weeds well even under environmental factors such as water leaching, overflow of paddy water and low temperature.

KEY WORDS) Azimsulfuron , bensulfuron-methyl, environmental factors, perennial sedges

Introduction

Azimsulfuron (1-(4,6-Dimethoxy-pyrimidin-2-yl)-3-[2-methyl-4-(2-methyl-2H-tetrazol-5-yl) -2H-pyrazole-3-sulfonyl]-urea) (Fig.1) is a highly active herbicide for use in paddy rice developed out of sulfonylurea group of chemistry by E.I. du Pont de Nemours and Co.Inc. Another sulfonylurea herbicide, bensulfuron methyl (BSM), is highly active sulfonylurea that effectively controls broad leaf and sedge weeds in transplanted and direct seeded rice [5,7] and is widely used in various paddy rice area of the world. In this study, we investigated the herbicidal activity of azimsulfuron and found out its higher activity on perennial sedge weeds than BSM. We have tried to combine azimsulfuron with BSM to make the best use of the advantage of each herbicide. We also investigated the effect of the environmental factors, leaching, overflow and low temperature, on the weed control of azimsulfuron in combination with BSM to make sure whether it gives the regional differences of herbicidal activity.

Materials and Methods

Compound

Chemical structure of azimsulfuron is shown in Fig. 1.

Assay of Acetolactate Synthase (ALS)

The leaves of ten days old etiolated soybean and wild mustard were used as a source of ALS. The preparation of crude enzyme and its assay were conducted by the same procedure as Ray did [3].

---

* Agricultural Science Laboratory, Agricultural Products, Du Pont Kabushiki Kaisha 25-2, 1-chome, Kannondai, Tsukuba-shi, Ibaraki 305 Japan

*** Agricultural Products Department, E.I du Pont de Nemours and Company, Inc. Wilmington, Delaware 19898, U.S.A.

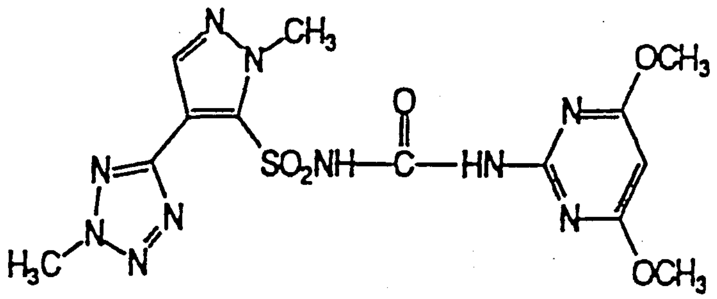


Fig.1. Chemical structure of azimsulfuron

Herbicidal Activity and Crop Safety Test in Greenhouse

Weed control and crop safety under paddy conditions were determined through the test in greenhouse. The test was conducted using plastic pots, 1/5000a and 1/10000a, filled with paddy soil (light clay, pH6.3, Organic Matter Content=4.2%). After adding fertilizer (N:P:K=12:16:1) and puddling, the weed seeds (former 3 species) or tubers (latter 3 species) (Monochoria vaginaris, Rotala indica , Scirpus juncoides, Sagittaria pygmaea , Cyperus serotinus and Eleochalis kuroguwai)were planted in the soil surface in 1/10000a pots and rice seedlings at the 2.2 leaf stage were transplanted in 1/5000a pots. The chemicals (technicals diluted in acetone) were applied to the paddy water. After that, the pots were kept in greenhouse for 35 days for weed control studies and 21 days for crop safety studies, and then weed control and crop injury were visually evaluated using a zero to 10 rating system (0=no effect, 10=complete killing).

Studies of Effects of Environmental Factors on Herbicidal Activity

(a). Effect of Leaching on Herbicidal Activity

Monochoria vaginaris, Rotala indica, Cyperus difformis and Scirpus juncoides were grown in 1/5000a Wagner pots filled with puddled paddy soil (clay loam, pH6.5, OM1.2%). Leaching was conducted at 2cm/day regulated by electric pump, and kept for 3 days just after chemical application.

(b). Effect of Overflow on Herbicidal Activity

The simulation study of overflow of paddy water by rainfall was conducted by the same method as Morita et al did [2] Monochoria vaginaris, Scirpus juncoides and Cyperus serotinus were grown in 1/10000a plastic pots filled with the puddled paddy soil. Three, 6 and 24 hours after chemicals applications, 200 ml of paddy water which is equivalent to 2cm water depth was exchanged with same volume of non-chemical fresh water. This water exchange simulated the rain fall at 50 mm / day.

(c). Effect of Low Temperature on Herbicidal Activity

Rotala indica, Scirpus juncoides and Cyperus serotinus were grown in the pots prepared by the same way as the herbicidal activity test in greenhouse, and were put in the two growth chambers one of which was controlled at 20°C/10°C (day/night) and another at 25°C/15°C (day/night). Chemicals were applied at the designated timing.

Table 1. Effect of azimsulfuron and BSM on ALS from wild mustard and soybean

PLANT	Azimsulfuron I50 (mole/l)	BSM I50 (mole/l)
WILD MUSTARD	3.1x10	1.0x10
SOYBEAN	2.0x10	1.9x10

Results

Assay of Acetolactate Synthase (ALS)

Azimsulfuron, like other sulfonylurea herbicides [3,6], inhibited the plant enzyme acetolactate synthase extracted from soybean and wild mustard and provided low I_{50} values, $2.0x10^{-7}$ mole/l (soybean) and $3.1x10^{-8}$ mole/l (wild mustard) (Table 1).

Herbicidal Activity and Crop Safety Test in Greenhouse

Azimsulfuron : Azimsulfuron at 6 g a. i. /ha gave better control on Cyperus serotinus and Eleochalis kuroguwai than BSM at 51 and 75 g a. i. /ha. At the same rates, azimsulfuron controlled Scirpus juncoides and Sagittaria pygmaea similarly as BSM but was less active on annual broad leaf weeds(Monochoria vaginaris and Rotala indica). The herbicidal symptoms of azimsulfuron were similar to that of BSM. Rice plants were tolerant to azimsulfuron and the slightly better crop safety than BSM at 51 g a.i. /ha has been given at 6 g a. i. /ha(Table 2).

BSM + Azimsulfuron : In greenhouse test, BSM at 24 and 36 g a. i. /ha in combination with azimsulfuron at 6 g a. i. /ha controlled Cyperus serotinus and Eleochalis kuroguwai better than BSM at 51 and 75 g a. i. /ha and controlled Monochoria vaginaris and Rotala indica better than azimsulfuron alone at 6ga.i./ha. Rice plants were tolerant to BSM+azimsulfuron at 24+6 and 36+6g a.i./ha as well as BSM at 51 and 75 g a. i. /ha (Table 3).

Studies of the Effects of Environmental Factors on Herbicidal Activity

(a). Effect of leaching on Herbicidal Activity

BSM+azimsulfuron at 30+6g a.i./ha and their half rate controlled every testedweeds, Monochoria vaginaris, Rotala indica , Cyperus difformis and Scirpus juncoides, even under leaching condition. On the other hand, azimsulfuron at 6ga.i./ha was not active enough on Monochoria vaginaris, Rotala indica and Cyperus difformis, and BSM at 51ga.i./ha was not active enough on Scirpus juncoides under leaching condition. At the half rates, azimsulfuron alone was not active enough on any tested weeds and BSM at 51 g a.i./ha was not active enough on Monochoria vaginaris, Rotala indica and Scirpus juncoides under leaching condition. BSM at 75 ga.i./ha and its half rate controlled every tested weed except for the fact that it was not active enough on Scirpus juncoides at half rate (Fig.2).

(b). Effect of Over Flow on Herbicidal Activity

BSM+azimsulfuron at 30+6ga.i./ha and its half rate provided high herbicidal activity on the tested weeds, Monochoria vaginaris, Scirpus juncoides and Cyperus serotinus, even with the over flow of the paddy water at 3, 6 and 24 hours after application though its activities at 1/3 rate were clearly reduced by the over flow at every timing tested, especially at 3 hours after application (Fig.3).

Table 2. Crop safety and herbicidal activity of azimsulfuron in greenhouse test

CHEMICALS	RATE (g a.i./ha)	CROP SAFETY* RICE (5DAT**)	HERBICIDAL ACTIVITY* Mv (2L)	Ri (1L)	Sj (3L)	Sp (3L)	Cs (3L)	Ek (15cm)
Azimsulfuron	6	1.5	7	3	8.5	8	10	10
	12	1.5						
BSM	51***	1.5	10	9.5	8.5	8.5	7	7
	102	2.5						
	75***	2	10	9.5	9	8	8	8
	150	3.5						

* Crop safety and herbicidal activity were visually evaluated using scales ranging from 0 to 10
** Application time (DAT : days after application, L : leaf stage)
Mv : Monochoria vaginalis, Ri : Rotala indica, Sj : Scirpus juncoides, Sp : Sagittaria pygmaea, Cs : Cyperus serotinus, Ek : Eleochalis kuroguwai
*** Actual rate for use in paddy fields in southern and northern areas, respectively.

Table 3. Crop safety and herbicidal activity of BSM+azimsulfuron in greenhouse test

CHEMICALS	RATE (g a.i./ha)	CROP SAFETY* RICE (5DAT**)	HERBICIDAL ACTIVITY* Mv (2L)	Ri (1L)	Sj (3L)	Sp (3L)	Cs (3L)	Ek (15cm)
BSM+Azimsulfuron	24+6	1.5	10	9.5	9	8	9	9.5
	36+6	2	10	9.5	9	8.5	9	9.5
Azimsulfuron	6	1	7	3	8.5	8	10	10
BSM	51	2	10	9.5	8.5	8.5	7	7
	75	2	10	9.5	9	8	8	8

* Crop safety and herbicidal activity were visually evaluated using scales ranging from 0 to 10
** Application time (DAT : days after application, L : leaf stage)
Mv : Monochoria vaginalis, Ri : Rotala indica, Sj : Scirpus juncoides, Sp : Sagittaria pygmaea, Cs : Cyperus serotinus, Ek : Eleochalis kuroguwai

(c). Effect of Low Temperature on Herbicidal Activity

BSM+azimsulfuron at 30+6ga.i./ha controlled tested weeds, Rotala indica, Scirpus juncoides and Cyperus serotinus, under the lower temperature condition, 20°C/10°C (day/night), as well as 25°C/ 15°C (day/night). The combination demonstrated higher activity on Rotala indica under the lower temperature condition (Table 4).

Discussion

Results through the test in greenhouse indicate that azimsulfuron at a rate as low as 6ga.i./ha provides excellent control on sedge and perennial weeds, whereas higher rate is required to give excellent control on annual broad leaf weeds. Especially the activity of azimsulfuron for controlling perennial sedges was significantly higher than that of BSM. Azimsulfuron at 6 and 12ga.i./ha provided slight injury on transplanted rice with the application at 5 days after transplanting, but the injury was comparable with BSM at 51 and 75ga.i./ha and was acceptable. In the test in greenhouse, we could see a clear advantage of combining azimsulfuron with BSM ; azimsulfuron at 6 ga.i./ha plus BSM at 24-36 ga.i./ha. Addition of azimsulfuron could significantly increase the activity of BSM on perennial sedge weeds without increasing crop injury, and reduced total quantity of chemicals from 51 g a.i./ha to 30-42 g a.i./ha.

BSM + azimsulfuron controlled the tested weeds well even with environmental factors such as leaching, overflow of paddy water and low temperature. The

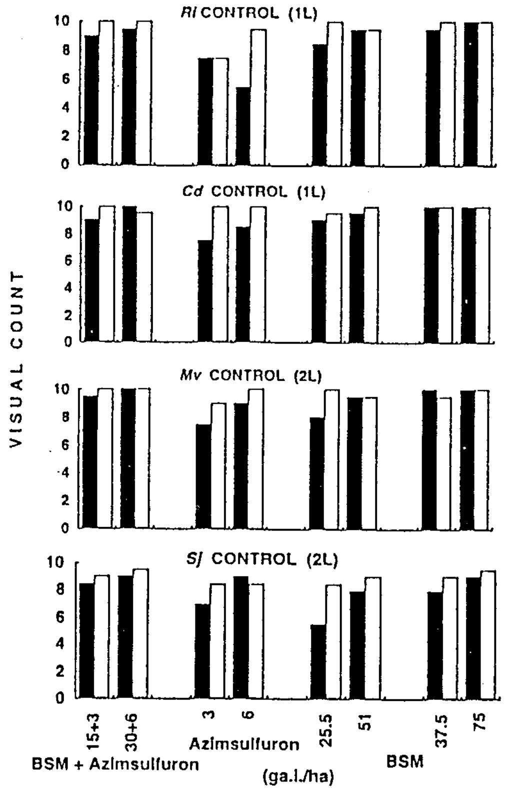


Fig. 2. Effect of leaching (2 cm/day for 3 days) on herbicidal activity of BSM + azimsulfuron, azimsulfuron and BSM
■ Leaching □ Non - leaching

Rl : Rotala indica, Cd : Cyperus difformis, Mv : Monochoria vaginalis, Sj : Scirpus juncoides

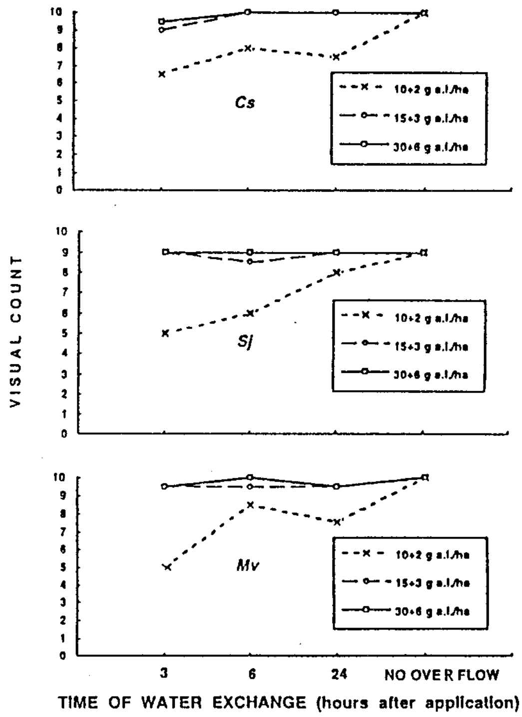


Fig. 3. Effect of overflow on herbicidal activity of BSM + azimsulfuron

Cs : Cyperus serotinus, Sj : Scirpus juncoides, Mv : Monochoria vaginalis

Table 4. Effect of low temperature on herbicidal activity of BSM+azimsulfuron and BSM

CHEMICALS	RATE (g a.i./ha)	HERBICIDAL ACTIVITY * 20/10 C *Ri* (1L)	*Sj* (2L)	*Cs* (3L)	25/15 C *Ri* (1L)	*Sj* (2L)	*Cs* (3L)
BSM+Azimsulfuron	15+3	10	9	9	9	9	9.5
	30+6	10	9	10	9	9	10
BSM	37.5	9.5	8.5	6	9	8	4
	75	9.5	9	8.5	9.5	9	7

* Herbicidal activity was visually evaluated in scales ranging from 0 to 10.

higher herbicidal activity of BSM+azimsulfuron than each sulfonylurea herbicide alone under leaching condition demonstrates the increasing stability of weed control by the combination. As for overflow test, since the tested extruded granule of BSM and azimsulfuron tend to provide their highest concentration in paddy within 24 hours after application (data not shown)[8], the timing of overflow shown above (3, 6 and 24 hours after application) seems to be relatively severe for weed control of the compounds. That is, it was suggested that BSM+azimsulfuron keeps its high activity on paddy weeds even under the condition with the rainfall at early timing after application. In terms of low temperature response, the mixture of BSM and azimsulfuron gives neither increase or decrease of practical weed control on Scirpus juncoides and Cyperus serotinus but was a little more active on Rotala indica under low temperature condition, while BSM alone increased its activity on Cyperus serotinus. Better weed control of rice herbicides under low temperature condition are reported with cinmethlyn [1] and pyrazosulfuron-ethyl [4]. These results of the studies of environmental factors demonstrated that the weed control of the combination of BSM at 30 g a.i./ha and azimsulfuron at 6ga.i./ha is stable under the possible environmental factors for variables.

These test results suggest that azimsulfuron is a promising rice herbicide which has high biological activity and good crop safety especially in combination with BSM with lower total use rate.

References

1. Jones,R.C., T. Iinuma and M. W. Murphy 1987.
WL95481-a novel herbicide for use in flooded transplanted rice.
Proceeding of the 11th Asian Pacific Weed Science Society, 407-413.
2. Morita, H., S.Eguchi, S. Nakayama and M. Miyahara 1989.
Fluctuation of Efficacy in Several Rice Herbicides under Continuous Raining Condition (in Japanese).
Weed Res., Japan 34 (Suppl.), 41-42.
3. Ray, T. B. 1984
Site of action of chlorsulfuron - Inhibition of valine and isoleucine biosynthesis in plants.
Plant Physiol. 75, 827-831.
4. Suzuki, K., T. Nawamaki and S. Watanabe 1994.
The effect of environmental factors on the herbicidal activity of pyrazosulfuron-ethyl under paddy conditions.
Weed Res., Japan 39 (1), 46-51.
5. Takeda,S., T. Yuyama, R.C.Ackerson, R.C.Weigle, R.F.Sauers, L.W.Neal, D.G.Gibian and P.K.Tseng 1985.
Herbicidal activity and selectivity of a new rice herbicide DPX-F5384.
Weed Res.,Japan 30 (4), 284-289.
6. Takeda,S., D.L.Erbes, P.B.Sweetser, J.V.Hay and T.Yuyama 1986.
Mode of selective action of DPX-F5384 between rice and weeds.
Weed Res.,Japan 31(2), 157-163.
7. Yuyama,T., S.Takeda, H.Watanabe, T.Asami, S.Peudpaichit, J.L.Malassa and P.Heiss 1983.
DPX-F5384 - A new broad spectrum rice herbicide.
Proceeding of the 9th Asian Pacific Weed Science Society, 554-559.
8. Yuyama,T., R.C.Ackerson, S.Takeda and Y.Watanabe 1987.
Soil and water relationships of bensulfuron methyl (DPX-F5384) under the paddy field condition.

KIH-2023, A NEW POST-EMERGENCE HERBICIDE IN RICE *(Oryza sativa)*

K.Kobayashi[1]*, M. Yokoyama[1], O. Watanabe[1], H. Sadohara[1], N. Wada[2]
([1] Kumiai Chemical Industry Co., Ltd., [2] K-I Chemical Research Institute Co., Ltd.)

Abstract. KIH-2023, sodium 2,6-bis[(4,6-dimethoxypyrimidin-2-yl)oxy]benzoate, is a new post-emergence herbicide for the control of a wide range of weeds with excellent selectivity in direct seeded rice (*Oryza sativa*). This compound inhibits acetolactate synthase in plants. The rate of 15 to 45 g a.i./ha with surfactant has provided outstanding efficacy on *Echinochloa* spp. and can be applied from one to seven leaf stage of the weed. Also it can control other important weeds including *Cyperus* spp., *Fimbristylis* spp., *Scirpus* spp., *Sagittaria* spp., and *Sphenoclea zeylanica.* Rice exhibits good tolerance to KIH-2023 at this rate. Preliminary results are favorable in toxicological and environmental fate studies.

Keywords : KIH-2023, bispyribac-sodium, rice herbicide, direct seeded rice

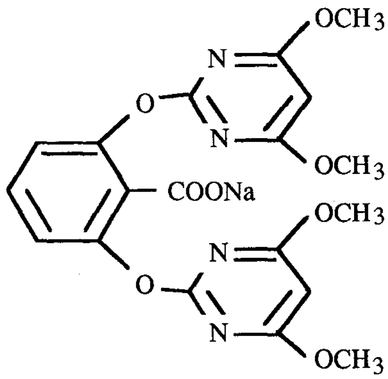
Introduction

In direct seeded rice, some annual and perennial weeds, especially *Echinochloa* spp. frequently escape from application of existing commercial rice herbicides which usually require relatively high rates of use. Rice growers continue to look for flexible and low rate post-emergence herbicide to optimize crop yield. KIH-2023 (common name : bispyribac-sodium) is a new post-emergence herbicide discovered and being developed by Kumiai Chemical Industry Co., Ltd. for use in direct seeded rice. This herbicide inhibits acetolactate synthase in plants, and exhibits excellent efficacy against a wide range of economically important grass and broadleaf weeds with good safety. This paper describes the biological properties of KIH-2023 from greenhouse trials.

Materials and Methods

Chemical and Physical Properties

Structure :



Common name	: bispyribac-sodium (ISO proposed)
Chemical name	: Sodium 2,6-bis[(4,6-dimethoxypyrimidin-2-yl)oxy]benzoate (IUPAC)
Chemical formula	: $C_{19}H_{17}N_4NaO_8$
Appearance	: White powder
Molecular weight	: 452.4

Melting point	: 223 ～ 224 ℃
Water solubility	: 73.3 g/l (at 25 ℃)
Vapour pressure	: 5.04 x 10^{-9} Pa (at 25 ℃)

Toxicology

Acute oral LD50 (rat)	: 4111 mg/kg (male), 2635 mg/kg (female)
Acute dermal LD50 (rat)	: > 2000 mg/kg
Inhalation LC50 (rat)	: > 4.48 mg/l
Acute fish toxicity LC50	: Bluegill sunfish : >100 ppm
	Rainbow trout : > 100 ppm
Eye irritation (rabbit)	: Slightly irritant
Skin irritation (rabbit)	: Not irritant
Ames mutagenicity	: Negative
Teratogenicity (rat, rabbit)	: Non-teratogenic
Subchronic toxicity	: No effect level, rat : 100 ppm (male), 1000 ppm (female)
	dog : 100 mg/kg/day (male, female)

Biological trials

Greenhouse trials were conducted using 10% W.P. or 30% D.F. formulation. Clay loam soil was used. Visual evaluation of herbicidal effects were made 30 days after application using a scale of zero to ten (zero= no effect to ten = complete control). Trials contained three replicates. Test plants and application methods were as follows.

1. Activity of KIH-2023 in different rice cultivation practices

KIH-2023 10% W.P. was tested under two conditions. One was dry seeded rice cultivation conditions without flooding water, and the other was transplanted rice cultivation conditions. KIH-2023 was applied, by dropping diluted solution, on to the flooding water of the simulated transplanted rice cultivation pots. KIH-2023 was also sprayed on the foliage of the test plants of simulated dry seeded rice cultivation pots. Applications were made in 1000 l/ha spray volume with a non ionic surfactant at 0.1 % V/V. *Echinochloa* was in the three leaf stage at application.

2. Selectivity of KIH-2023 between rice and *Echinochloa* in foliar application

Rice (var. IR36) and *Echinochloa oryzicola* were grown in plastic pots without flooding water. KIH-2023 was sprayed on the foliage of the plants. Applications were made in 1000 l/ha spray volume with a non ionic surfactant at 0.1 % V/V.

3. Activity of KIH-2023 under flooded conditions

Rice (var. IR36) and *Echinochloa oryzicola* were grown in plastic pot with water depth of 4 cm flooding. The test plants were in the four to six leaf stage. Foliar applications were made in the same manner as in trial two.

4. Effect of surfactant on activity of KIH-2023

Echinochloa oryzicola was grown without flooding water. Foliar applications were made in 1000 l/ha spray volume with, or without, a non ionic surfactant at 0.1% V/V. *Echinochloa* was in the five leaf stage at application..

5. Weed spectrum of KIH-2023 in foliar application

Aquatic weeds were grown under 4 cm flooding conditions. Other weeds were grown without flooding water. *Echinochloa oryzicola* was in the four leaf stage at application. The water was drained from the aquatic weeds pots at the time of application. The aquatic weeds were flooded again at three days after application.

KIH-2023 30% D.F. were used in the trials from number two through five.

Results and Discussion

KIH-2023 has little activity when applied on the flooding water under transplanted rice cultivation conditions. Under dry seeded rice cultivation conditions, however, KIH-2023 at 7.5 g a.i./ha provides excellent control on *Echinochloa* with good tolerance of rice (Table 1).

Table 1. Activity of KIH-2023 in different rice cultivation practices.

Cultivation type	Application method	Rate (g a.i./ha)	*Echinochloa* control	Rice injury
transplanted	drop	7.5	0	0
		15	0	0
		30	0	0
		60	1	2
dry seeded	foliar	7.5	10	0
		15	10	1
		30	10	3
		60	10	3

evaluation scale : 0 = no effect - 10 = complete control

The results of selectivity trial are shown in Figure 1. KIH-2023 has high selectivity between rice and *Echinochloa oryzicola* with foliar application under dry seeded conditions, especially when rice is three leaf stage or older. The efficacy of KIH-2023 on *Echinochloa oryzicola* seemed to be consistent control on wide range of growth stage of *Echinochloa oryzicola* under dry seeded conditions. KIH-2023 at 15 to 30 g a.i./ha provides better control than Propanil at 3000 g a.i./ha on *Echinochloa oryzicola* when test plants were in the three to seven leaf stage (Figure 2). These results suggest that KIH-2023 can be used against a wide range of growth stage of rice plants and *Echinochloa* spp..

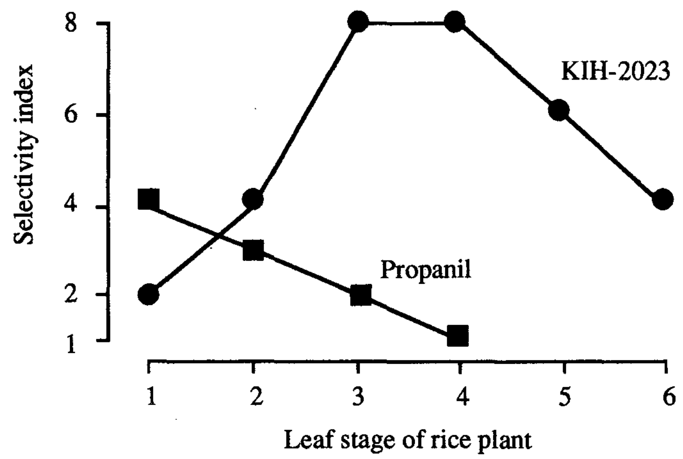


Figure 1. Selectivity of KIH-2023 between rice and *Echinochloa oryzicola* by foliar application under dry seeded conditions.

$$\text{Selectivity index} = \frac{\text{Rate required for 10\% rice injury}}{\text{Rate required for 90\% } \textit{Echinochloa oryzicola} \text{ control}}$$

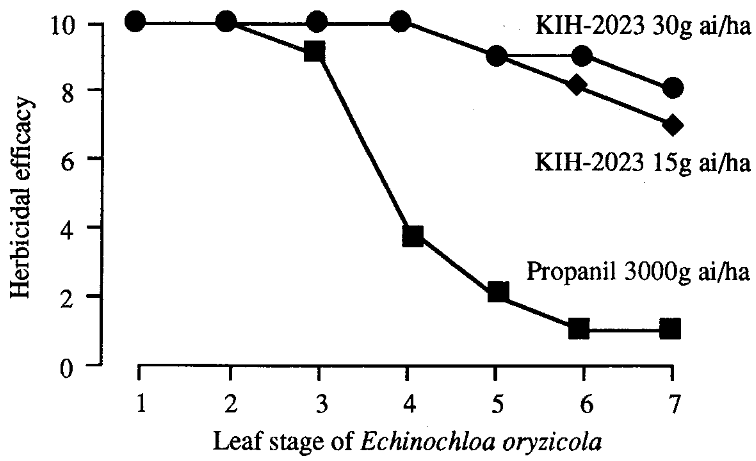


Figure 2. Efficacy of KIH-2023 on different growth stage of *Echinochloa oryzicola* by foliar application under dry seeded conditions.
evaluation scale : 0 = no effect - 10 =complete control

Table 2 shows activity of KIH-2023 under flooded conditions. KIH-2023 shows excellent control of *Echinochloa oryzicola* without rice injury at 15 to 30 g a.i./ha.
Activity of KIH-2023 remarkably decline when surfactant was not added to spray solution. Surfactants, including non-ionic types, silicon types and crop oil concentrates, play an important role in enhancing activity and achieving the consistent performance of KIH-2023 (Table 3).

Table 2. Activity of KIH-2023 under flooded conditions at different growth stage of *Echinochloa oryzicola.*

Test compound	Application* timing	Rice injury 30	60	*Echinochloa* control 15	30 (g a.i./ha)
KIH-2023	4 L	0	1	9	10
	5 L	0	1	8	10
	6 L	0	0	8	10

* : Leaf stage of *Echinochloa oryzicola*
evaluation scale : 0 = no effect - 10 = complete control

Table 3. Effect of surfactant on *Echinochloa* control of KIH-2023.

Test compound	Rate (g a.i./ha)	*Echinochloa* control not added	with surfactant
KIH-2023	7.5	0	8
	15	0	10
	30	0	10

evaluation scale : 0 = no effect - 10 = complete control

Table 4 Weed spectrum of KIH-2023 by foliar application

Test weed	Rate (g a.i./ha) 7.5	15	30
Grasses			
Echinochloa colonum	10	10	10
Echinochloa crus-galli	10	10	10
Echinochloa oryzicola	10	10	10
Echinochloa crus-pavonis	10	10	10
Digitaria ciliaris	6	7	8
Eleusine indica	2	6	7
Leptochloa chinensis	4	5	8
Leptochloa panicea	7	8	9
Brachiaria platyphylla	8	9	10
Sedges			
Cyperus difformis	9	10	10
Cyperus iria	9	10	10
Cyperus serotinus	4	8	8
Fimbristylis miliacea	-	10	10
Scirpus juncoides	6	7	9
Eleocharis kuroguwai	2	4	9
Broad leaf weeds			
Aeschynomene indica	10	10	10
Alisma canaliculatum	8	9	9
Amaranthus retroflexus	9	10	10
Eclipta thermalis	9	10	10
Lindernia procumbens	10	10	10
Ludwigia epilobioides	10	10	10
Monochoria vaginalis	5	9	10
Polygonum lapathifolium	9	10	10
Portulaca oleracea	9	10	10
Rotala indica	10	10	10
Sagittaria pygmaea	5	8	10
Sagittaria trifolia	5	7	10
Sphenoclea zeylanica	-	7	9

evaluation scale : 0 = no effect - 10 = complete control
- : not tested

Table 4 shows that weed spectrum of KIH-2023 at 7.5, 15 and 30 g a.i./ha in foliar application. KIH-2023 is able to control *Echinochloa* spp. and other important weeds in direct seeded rice including grasses, sedges and broad leaf weeds.

Conculutions

The results of these trials show KIH-2023 with surfactant has wide application window and wide weed spectrum in foliar application. KIH-2023 exhibits excellent control on *Echinochloa* spp. with good crop safety. The properties of KIH-2023 seen in these trials allow it to be considered a basic tool for weed control in direct seeded rice.

References

1. Yokoyama, M., O. Watanabe, K. Kawano, S. Shigematsu, 1993, KIH-2023, A New Post-Emergence Herbicide in Rice, Brighton Crop Protection Conference - Weeds -, 61 - 66.

2.Yokoyama, M., O. Watanabe, K. Yanagisawa, N. Wada, S. Shigematsu,1994, KIH-2023, Studies on a New Herbicide KIH-2023 (1), Herbicidal Activity and Selectivity of Pyrimidinyloxy Benzoate Derivatives, Weed Research, Japan 39 Supplement Ⅰ, 30-31

3.Yokoyama, M., O. Watanabe, K. Yanagisawa, Y. Ogawa, N. Wada, S. Shigematsu,1994, KIH-2023, Studies on a New Herbicide KIH-2023 (2), Characterization of KIH-2023 as a Herbicide in Paddy Field, Weed Research, Japan 39 Supplement Ⅰ, 32-33

Imazosulfuron, a New Sulfonylurea Herbicide, Applicable in Rice Paddy Fields

Y.Tanaka*, K.Ideno, T.Yamawaki and H.Yoshikawa
Agricultural Research Laboratories, Agro Division,
Takeda Chemical Industries, Ltd., Tsukuba, Ibaraki 300-42, Japan

Abstract. Imazosulfuron, which is a new herbicide synthesized and developed by Takeda Chemical Industries, Ltd. for use in paddy rice and in turf, was studied for biological activity and selectivity. Imazosulfuron controlled 12 paddy field weeds including annual and perennial broadleaf weeds and sedges on pre- and post-emergence applications of 90 g ai/ha, the conventional dosage eventually adopted for practical use. Rice plants on applications of 75 g ai/ha to 150 g ai/ha of imazosulfuron did not suffer any practical damage irrespective of planting depths and water leakage conditions. The results and accompanying data show that imazosulfuron exerts excellent herbicidal activity on most paddy field weeds with sufficient safety to rice plants over a broad range of dosage centered at 90 g ai/ha. When AWARD® flowable, a milky suspension composed of three herbicides, i.e. imazosulfuron, pyributicarb and daimuron, was dripped into a rectangular paddy field(1 m x 16 m) where rice plants, *Echinochloa oryzicola*, *Scirpus juncoides* and *Cyperus serotinus* were equally grown, in a way as though a line had been drawn along the short side, most of the weeds were killed, while the rice plants were entirely unharmed. It is remarkable that the weeds 15m distant from the start line were damaged as much as those close to the line, and indicates the efficient dispersion of AWARD® flowable.

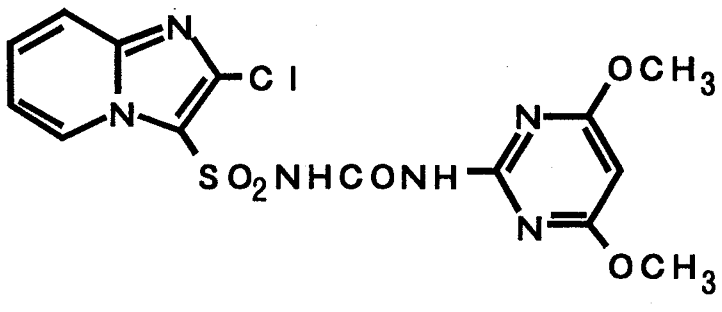
Key words. imazosulfuron, herbicidal activities, safety for rice plants, flowable formulation

INTRODUCTION

Imazosulfuron, a new sulfonylurea herbicide(1),(2), was commercialized in Japan in 1993. Various type of formulations such as TAKEOFF®, BATL®, HAYATE®, GO-SIGN® and AWARD® are now available for paddy field use(3). TAKEOFF® is a single granular formulation and BATL®, HAYATE® and GO-SIGN® are also granular formulations in combination with grass herbicides. AWARD® flowable is a suspension combination formulation and quickly dispersible when dripped or poured directly into paddy water.

This paper reports properties of imazosulfuron such as herbicidal activity, safety for rice plants, selectivity and dispersibility of AWARD® flowable.

Chemical and physical properties
Common name : imazosulfuron (ISO)
Code name : TH-913
Chemical name : 1-(2-chloroimidazo[1,2-*a*]pyridin-3-ylsulfonyl)-3-(4,6-dimethoxy-pyrimidin-2-yl) urea (IUPAC)
Structural formula :



Molecular weight : 412.83
Melting point : 183-184℃ (dec.)

Solubility(at 25°C) : water

pH	5.1	6.1	7.0
mg/l	5	67	308

Toxicological properties

Acute oral	: mouse	(male and female)	LD50 > 5000 mg/kg
	rat	(male and female)	LD50 > 5000 mg/kg
Acute dermal	: rat	(male and female)	LD50 > 2000 mg/kg
Skin irritation	: rabbit	not irritant	
Eye irritation	: rabbit	not irritant	
Mutagenicity	:	negative	
Fish toxicity	: carp	TLm48hr > 10 ppm	

MATERIALS AND METHODS

Herbicidal activity

Herbicidal spectrum

Weed seeds or tubers are planted uniformly into the flooded soil in a 200 cm^2 plastic Wagner pot packed with clay loam soil(Organic matter 5.11%), keeping flooding water constant in 5 cm depth during the experiments(similar Wagner pots packed with the soil were used in the following experiments). Immediately after the planting or when weeds reached the specific stages shown in Fig.1, 0.3% granules of imazosulfuron were applied to the flooding water at the dosage of 30 kg/ha. 21 days or 28 days after applications, the above-ground parts of weeds were cut off and the dry weights were measured after oven-dried at 70°C for 24 hours.

Residual activity

0.25% granules of imazosulfuron were applied to the flooding water at the dosage of 30 kg/ha. Immediately after the application or 14, 28 and 42 days after the application, seeds of *Scirpus juncoides* and tubers of *Sagittaria pygmaea* and *Cyperus serotinus* were planted into the flooded soil in the Wagner pots. After 21 days from the planting, weed control(%) was evaluated visually with scales ranging from 0(same as the untreated) to 100(complete killing).

Safety for rice plants

Effect of transplanting depths

Rice seedlings(*Oryza sativa* cv. Nihonbare) at 2 leaf stage were transplanted into the flooded soil in the Wagner pots in −0.5 cm, 1 cm, or 3 cm depth. 5 days after transplanting, 0.25% granules of imazosulfuron were applied to the flooding water at the dosages of 30 kg/ha or 60 kg/ha. 28 days after applications, shoots were cut off and the dry weights were measured after oven-dried at 70°C for 24 hours.

Effect of water leakage

Rice seedlings at 2 leaf stage were transplanted into the flooded soil in the Wagner pots in 2 cm depth. 7 days after transplanting, 0.25% granules of imazosulfuron were applied to the flooding water at the dosages of 40 kg/ha or 60 kg/ha and then water was leaked at the rate of 3 cm/day in depth for 3 days. Water depth was maintained at 5 cm during the experiments. 35 days after applications, shoots were cut off and the dry weights were measured after oven-dried at 70°C for 24 hours.

Diference of sensitivity between *C. serotinus* and rice plants

The tubers of *C. serotinus* were planted into the flooded soil in the Wagner pots. When *C. serotinus* reached its 1 to 2 leaf stage, a suspension solution of imazosulfuron was applied to the flooding water at the dosages of 1, 3, 10, 30 and 100 g ai/ha. 28 days after applications, their above-ground parts were cut off and the dry weights were measured after oven-dried at 70°C for 24 hours. Rice seedlings at 2 leaf stage were transplanted into the flooded soil in the Wagner pots. 7 days after transplanting, a suspension solution of imazosulfuron was applied to the flooding water at the dosages of 30, 100, 300, 1000 and 3000 g ai/ha. 28 days after applications, the shoots were cut off and the dry weights were measured after oven-dried at 70°C for 24 hours.

Dispersibility of AWARD® flowable

Seeds of *Echinochloa oryzicola* and *S. juncoides* and tubers of *C. serotinus* were planted into the flooded soil in a rectangular paddy field(1 m x 16 m) at the intervals of 1m along the long side and rice seedlings at 2 leaf stage were transplanted equally all over the plot. Flooding water was kept in 5 cm depth during the experiments. 10 days after transplanting, *E. oryzicola*, *S. juncoides* and *C. serotinus* reached 1.7, 1.0 and 1.8 leaf stage, respectively. And then AWARD® flowable at the practical dosage of 5 *l*/ha was dripped into flooding water as though a line had been drawn along the short side. 17 days after the applications, the plant heights of transplanted rice were measured. After 35 days, the weeds were cut off and the dry weights were measured after oven-dried at 70℃ for 24 hours.

RESULTS AND DISCUSSION

Herbicidal activity

Herbicidal spectrum

As shown in Fig.1, all weeds were controlled extensively. Especially annual broadleaf weeds(*Monochoria vaginalis*, *Lindernia procumbens* and *Rotala indica*) at cotyledon stage and perennial weeds(*S. pygmaea*, *Sagittaria trifolia*, *Oenanthe javanica*, *Potamogeton distinctus*, *S. juncoides* and *C. serotinus*) were strongly suppressed to the degrees above 95%. Imazosulfuron inhibited shoot growth and killed them gradually. Although the dry weight of *E. oryzicola*, *Scirpus planiculmis* and *Eleocharis kuroguwai* were reduced more than 85%, they were alive while being stunted. On pre-emergence applications, some of emerged *E. oryzicola* elongated to coleoptile or 1 leaf stage and then all stunted.

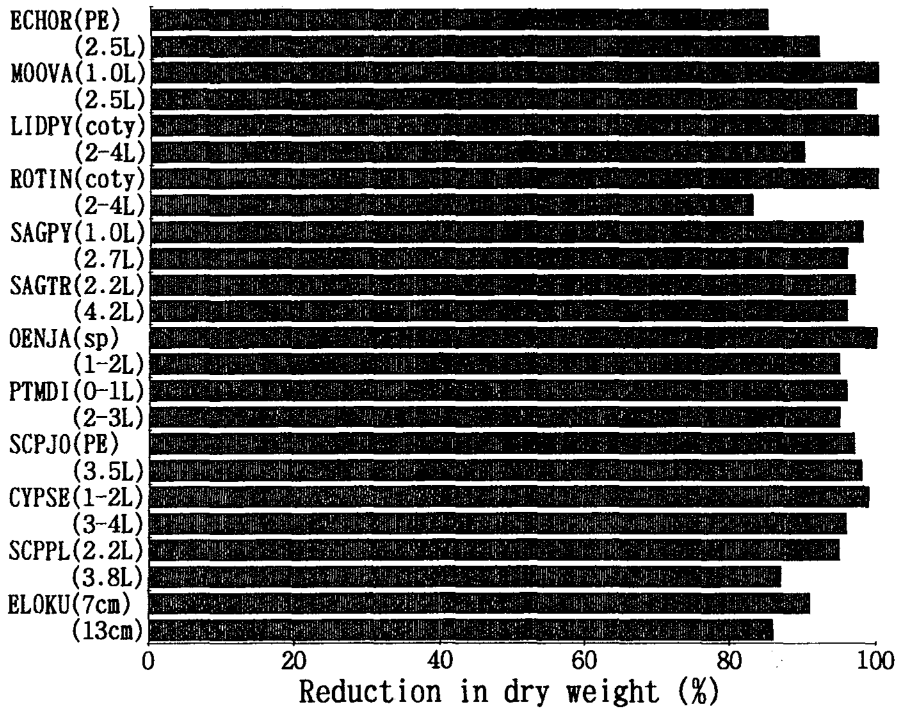


Fig.1 Effect of imazosulfuron(90 g ai/ha) on 12 paddy field weeds.

Abbreviations of weed names:

ECHOR : *Echinochloa oryzicola*,	OENJA : *Oenanthe javanica*
MOOVA : *Monochoria vaginalis*,	PTMDI : *Potamogeton distinctus*
LIDPY : *Lindernia procumbens*,	SCPJO : *Scirpus juncoides*
ROTIN : *Rotala indica*,	CYPSE : *Cyperus serotinus*
SAGPY : *Sagittaria pygmaea*,	SCPPL : *Scirpus planiculmis*
SAGTR : *Sagittaria trifolia*,	ELOKU : *Eleocharis kuroguwai*

Numbers and letters in parentheses show leaf stages or plant heights at applications.

Abbreviations of letters in parentheses:

PE : pre-emergence stage	coty : cotyledon stage
L : leaf stage	sp : sprouting stage

Residual activity

As shown in Fig.2, emergences of *S. juncoides*, *S. pygmaea* and *C. serotinus* were suppressed for 42 days. After 28 days, however, some of *S. pygmaea* and *S. juncoides* began to emerge and elongated to coleoptile or 1 leaf stage but all remained stunted without further growth.

Imazosulfuron was proved to have an excellent herbicidal activity on most paddy field weeds with sufficient residual activity.

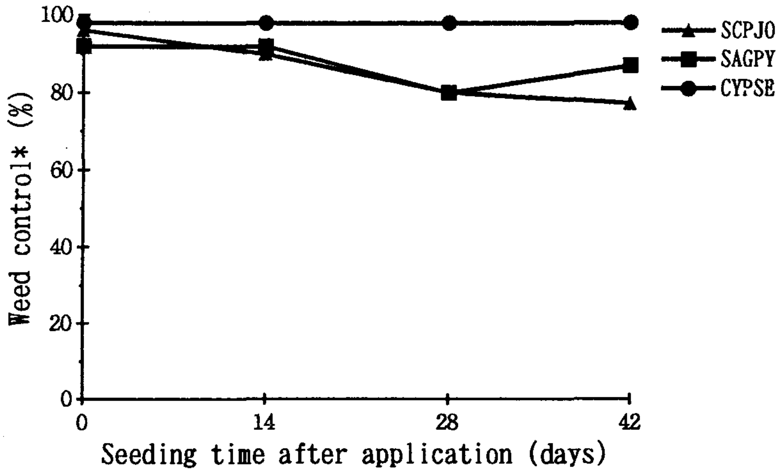


Fig.2. Residual activity of imazosulfuron(75 g ai/ha) on SCPJO, SAGPY and CYPSE.
*0 = same as the untreated; 100 = complete kiling.
For abbreviations of plant names see footnote in Fig.1.

Safety for rice plants

Effect of transplanting depths

As shown in Fig.3, at the applications of 75 g ai/ha, imazosulfuron did not cause any practical damage against transplanted rice even if transplanting depths were changed as −0.5 cm, 1 cm and 3 cm. In case of shallow transplanting(−0.5 cm in depth) only slight growth retardation and reduction of the dry weights were observed at the higher dosage of 150 g ai/ha but they did not result in any practical damage.

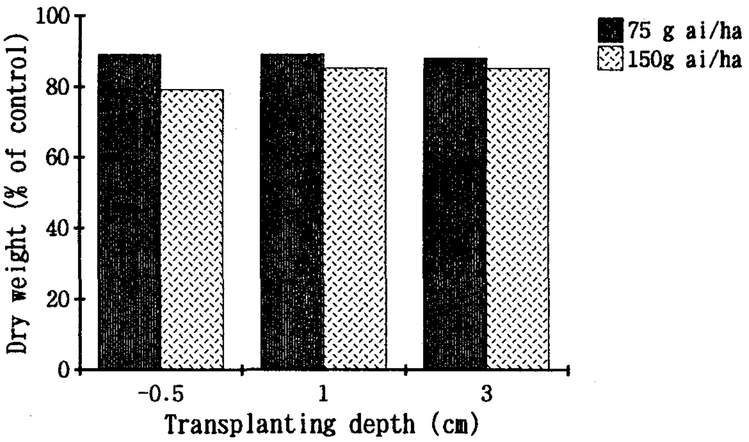


Fig.3. Effect of transplanting depth on the phytotoxicity of imazosulfuron against rice seedlings.

Effect of water leakage

As shown in Fig.4, water leakage did not cause any practical damage against transplanted rice. Although at 150 g ai/ha, a higher dosage than conventional one(90 g ai/ha), the dry weights of shoots were scarcely reduced by water leakage at the rate of 3 cm/day for 3 days.

It is remarkable that imazosulfuron nearby the conventional dosage(90 g ai/ha) did not cause any practical damage against transplanted rice irrespective of planting depths and water leakage conditions.

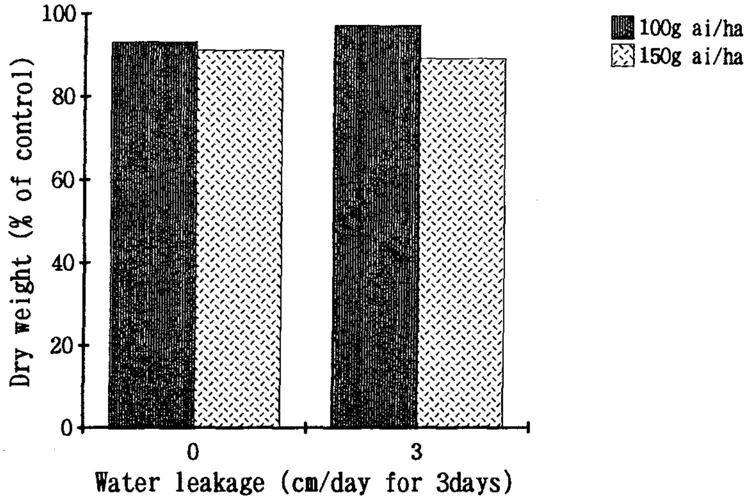


Fig.4. Effect of water leakage on the phytotoxicity of imazosulfuron to rice seedlings.

Difference of sensitivity between *C. serotinus* and transplanted rice

As shown in Fig.5, *C. serotinus* was completely suppressed and killed at the dosage over 10 g ai/ha. At the rate of less than 3 g ai/ha, the plants were only stunted with mild chlorosis and progressive necrosis as secondary symptoms. On the other hand, transplanted rice suffered only slight reduction in the dry weights at the dosage of 100 g ai/ha and the extent of the damage was acceptable. However, at the dosage over 1000 g ai/ha, transplanted rice was seriously injured and unrecoverable.

The I_{50} of imazosulfuron to *C. serotinus* was about 1000 times smaller than that to transplanted rice.

Imazosulfuron was proved to have excellent herbicidal activity against *C. serotinus* with sufficient safety to transplanted rice over a broad range of dosage centered at 90 g ai/ha.

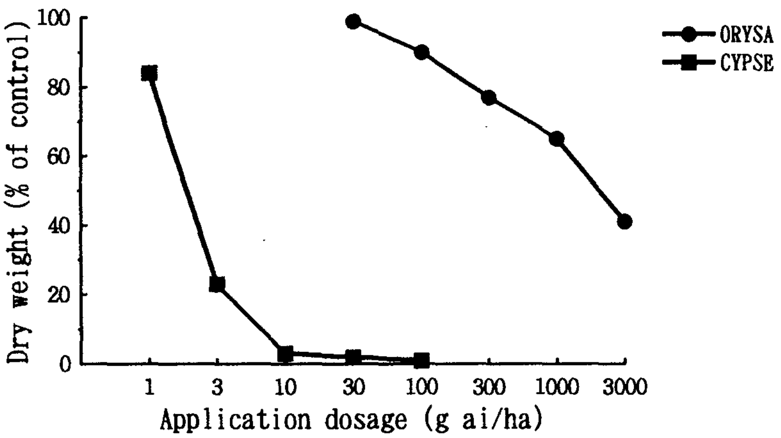


Fig.5 Difference of sensitivity between CYPSE and ORYSA to imazosulfuron.
CYPSE : *Cyperus serotinus*
ORYSA : *Oryza sativa*

Dispersibility of AWARD® flowable in a rectangular paddy field

As shown in Fig.6, at the location, 15 m apart from the application line, the dry weights of *E. oryzicola*

oryzicola and *C. serotinus* were suppressed to the degrees over 95%. In case of *S. juncoides*, a slight decline of weed control was observed at the locations 10 m or more apart from the application line but it was acceptable for practical use. On the other hand, transplanted rice did not suffer any damage even if at the neighboring area to the application line.

It is remarkable that AWARD® flowalble had shown good dispersibility to be able to control the weeds even at 15 m apart from the application line without damage to transplanted rice.

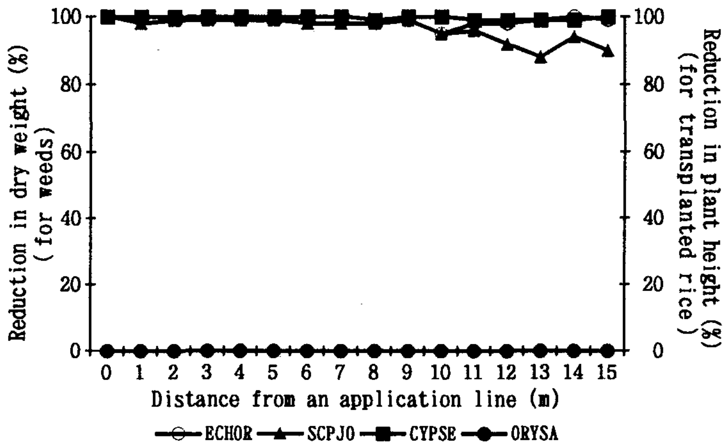


Fig.6 Dispersibility of AWARD® flowable in a rectangular paddy field.
For abbreviations of plant names see footnote in Fig.1

Note. Seeds of *E. oryzicola* and *S. juncoides* and tubers of *C. serotinus* were planted into the flooded soil in a rectangular paddy field(1 m x 16 m) at the intervals of 1 m along the long side and rice seedlings at 2 leaf stage were transplanted equally all over the plot. Flooding water was kept in 5 cm depth during the experiments. 10 days after transplanting, *E. oryzicola, S. juncoides* and *C. serotinus* reached 1.7, 1.0 and 1.8 leaf stage, respectively. And then AWARD® flowable at the practical rate of 5 *l*/ha was dripped into flooding water as though a line had been drawn along the short side. 17 days after applications, the plant heights of transplanted rice were measured. After 35 days, the weeds were cut off and the dry weights were measured after oven-dried at 70℃ for 24 hours.

REFERENCES

1. Ishida, Y., K.Ohta, S.Itoh, T.Nakahama, H.Miki and H.Yoshikawa 1993. J. Pesticide Sci. 18, 175.
2. Ohta, K., S.Itoh, J.Yamada, K.Masumoto, H.Yoshikawa and Y.Ishida 1993. J. Pesticide Sci. 18, 183.
3. Yamawaki, T., T.Nagai, Y.Tanaka and H.Yoshikawa 1994. Weed Res.(Japan)(Suppl.39) 24.(in Japanese)

AC 322,140: A New Broad-Spectrum Herbicide for Transplanted and Wet Sown Rice in the Far East

R. L. Braddock[1], S. C. Lee[2], P. J. Huang[3], C. Sujin[4]

[1] American Cyanamid Company, Princeton, New Jersey 08543-0400 USA
[2] Cyanamid International, Singapore
[3] Cyanamid Taiwan Corporation, Taiwan
[4] Cyanamid (Thailand) Limited, Thailand

Abstract. AC 322,140 is a new sulfamoylurea herbicide for selective weed control in paddy rice. The acetohydroxyacid synthase (AHAS) inhibitor is characterized by very low toxicity to mammals, birds, fish and aquatic invertebrates. Low water solubility and moderate to strong adsorption by soil also indicate a low potential for leaching. .Rice tolerance is primarily due to rapid metabolism. Field studies conducted in Asia at rates of 15 to 60g ai/ha applied 0 to 15 days after transplanting or seeding have demonstrated good to excellent control of a wide range of common annual and perennial broad-leaved weeds and sedges. Good crop tolerance has been demonstrated at rates up to 80g ai/ha. Initial registrations are anticipated by 1996-1997.

Key words: herbicide, rice, sulfamoylurea, broadleaf weed, sedge

Introduction

AC 322,140, (1-{[*0*-(cyclopropylcarbonyl)phenyl]sulfamoyl}-3(4,6-dimethoxy-2-pyrimidinyl)-urea) is a herbicide from a new chemical class (sulfamoylureas) developed by American Cyanamid Company. The mode of action of AC 322,140 is via inhibition of acetohydroxyacid synthase, a key enzyme in amino acid biosynthesis. AC 322,140 has been extensively field tested in transplanted rice and wet sown rice in Japan, Korea, PRC, Taiwan, and several South East Asian countries since 1992. This paper describes field performance of AC 322,140 in the PRC, Thailand, and Taiwan.

Materials and Methods

More than 10 transplanted and wet sown rice trials were completed in the PRC and Thailand, respectively, since 1992. Just as many transplanted rice trials were initiated in Taiwan during this period. Both AC 322,140 10% wettable powder (WP) and 0.15% extruded clay granule (G) formulations were tested. All trials were arranged in a complete randomized block design. Rates of AC 322,140 ranged from 15-80g ai/ha, using pre-emergence to post-emergence application (0-15 days timing). Local standards plus hand weeding and an untreated check were included for comparison.

Efficacy was determined by visual observation, number of major weed species, and fresh weight of weeds per unit area. Crop selectivity and yield were also assessed.

Results and Discussion

Herbicidal Activity

Field trials were conducted under different climatic and environmental conditions. The results presented summarize trials carried out in the cooler zone of Manchuria in the PRC, the moderately warm zone along the Yangtze River basin in the PRC and Taiwan, and in the warm zone in Thailand. The response of the major rice weed species to AC 322,140 at the dosage range of 15 to 80g ai/ha has been consistent throughout.

Grasses

AC 322,140 at 30-40g ai/ha gave good suppression of *Echinochloa crusgalli* (Table 1). This was seen in terms of weed coverage or weed biomass per unit area. For effective *Echinochloa* control, AC 322,140 required ≥ 60g ai/ha to be comparable to the standard grass herbicides in both transplanted and wet sown rice.

Table 1. AC 322,140: Effect on *Echinochloa crusgalli*, 1992-1994.

Treatment	Rate g ai/ha	Application Timing (DATR/DAS)	% Control at 30-50 DATR/DAS (1) PRC (2)	Taiwan (3)	Thailand (4)
AC 322,140	30	2-15	80.3	-	-
AC 322,140	40	2-15	86.3	70.0	67.8
AC 322,140	≥ 60	2-15	92.1	77.2	86.0
Butachlor (safened)	750	4	-	-	99.0
Butachlor	1350-1500	3-5	96.2	90.7	-
Molinate	3360	Post	98.2	-	-
Bensulfuron	30-45	2-15	68.6	69.7	-
Pyrazosulfuron	15-22.5	2-15	80.7	78.0	-
Pretilachlor	450	4	-	-	99.0
Untreated check	-	-	472.5 (5)	20.6% (6)	-

(1) - Days after transplanting or seeding.
(2) - Transplanted and wet sown rice. Average of 9 trials.
(3) - Transplanted rice. Average of more than 10 trials.
(4) - Wet sown rice. Average of more than 6 trials.
(5) - Weed biomass (g/m^2).
(6) - Ground cover of *Echinochloa crusgalli*.

In transplanted rice in the PRC, with good water management, AC 322,140 at 30-40g ai/ha appears sufficient to provide good suppression of this weed without resorting to selective hand weeding or sequential treatment with a late post-emergence grass herbicide.

Annual Broadleaf Weeds and Sedges

AC 322,140 at 20-30g ai/ha provided excellent control of many common annual broadleaf weeds and sedges such as: *Monochoria* spp., *Lindernia* spp., *Eclipta* spp., *Sphenoclea* spp., *Rotala* spp., and *Cyperus difformis*, irrespective of the application time. This near-perfect control was seen in all trials conducted in the various countries (Table 2). The 20g ai/ha rate appears more than adequate to provide acceptable control of these weeds.

Table 2. AC 322,140: Effect on Annual Broadleaf Weeds and Sedges - PRC, Taiwan and Thailand, 1992-1994.

			% Control at 30-50 DATR/DAS (1)						
			Broadleaf Weeds					Sedges	
Treatment	Rate g ai/ha FIMMI	Application Timing (DATR/DAS)	MONVA	LINPR	ECLPR	SPHZE	ROTIN	CYPDI	
AC 322,140	15	2-15	93.4	-	-	-	91.8	91.7	-
AC 322,140	20	2-15	90.8	98.0	93.0	-	98.6	96.3	-
AC 322,140	30	2-15	92.3	98.0	93.0	100.0	100.0	95.6	100
AC 322,140	40	2-15	98.3	98.0	96.3	100.0	100.0	98.8	100
Butachlor (Safened)	750	4	-	-	-	56.0	-	-	-
Butachlor	1350-1500	3-5	81.1	95.2	95.5	-	100.0	87.4	100
Pretilachlor	450	4	-	-	-	79.4	-	100.0	100
Bensulfuron	30-45	2-15	97.5	-	-	-	98.9	96.1	-
Pyrazosulfuron	15-22.5	2-15	97.5	-	-	-	98.0	92.5	-

(1) - Days after transplanting or seeding.

MONVA - *Monochoria vaginalis; M. korsakowii*
LINPR - *Lindernia procumbens; L. pyxidaria*
ECLPR - *Eclipta prostrata*
SPHZE - *Sphenoclea zeylanica*
ROTIN - *Rotala indica*
CYPDI - *Cyperus difformis*
FIMMI - *Fimbristylis miliacea*

Perennial Broadleaf Weeds and Sedges

Sagittaria pygmaea, S. trifolia, Potamogeton spp., and *Heleocharis yokoscensis* are widespread perennial weeds in the PRC. AC 322,140 at the 30 to 40g ai/ha rates consistently provided good control of these weeds (Table 3). There were a few escapes of *S. trifolia* and *Scirpus juncoides* (Taiwan), but they were greatly suppressed. The overall performance of AC 322,140 was comparable to the standard bensulfuron or pyrazosulfuron and distinctly superior to butachlor.

Table 3. AC 322,140: Effect on Perennial Broadleaf Weeds and Sedges - PRC, Taiwan and Thailand, 1992-1994.

			% Control at 30-50 DATR/DAS (1)						
			Broadleaf Weeds				Sedges		
Treatment	Rate g ai/ha	Application Timing (DATR/DAS)	SAGPY	SAGTR	POTDI	BIDTR	HELYO	SCIJU	SCIPL
AC 322,140	30	2-15	94.1	89.5	100	79.6	100	76.0	33.4
AC 322,140	40	2-15	99.1	86.5	100	89.9	100	86.4	57.3
AC 322,140	60	2-15	99.4	92.5	100	96.0	100	94.9	79.2
Bensulfuron	30-45	2-15	81.9	86.0	100	68.4	100	85.9	66.8
Pyrazosulfuron	15-22.5	2-15	92.6	89.0	100	76.0	100	88.0	76.1
Butachlor	1350-1500	3-5	98.6	54.0	100	0.0	0	68.0	0.0

(1) - Days after transplanting or seeding.

SAGPY - *Sagittaria pygmaea*
SAGTR - *S. trifolia*
POTDI - *Potamogeton distinctus*
BIDTR - *Bidens tripartita*
HELYO - *Heleocharis yokoscensis*
SCIJU - *Scirpus juncoides*
SCIPL - *Scirpus planiculmis*

AC 322,140 at the 40g rate also gave good control of *Bidens tripartita*, a new, emerging perennial in Manchuria rice of the PRC and in Korea. All rates of AC 322,140 below 60g ai/ha failed to control *Scirpus planiculmis*, a difficult-to-control perennial sedge, not easily managed by current standard sulfonylureas (Table 3).

Crop Tolerance and Effect on Paddy Yield

Both the japonica and indica rice varieties tested have shown good and acceptable crop tolerance, as well as good yield. Some transient dwarfing was noted, using the 60-80g ai/ha rates in both the transplanted and wet sown rice (PRC). However, paddy yield was not affected and was either comparable to or higher than the hand weeding treatment or untreated check (Table 4).

Table 4. AC 322,140: Effect on Rice Yield - PRC, Taiwan and Thailand, 1992-1994.

Treatment	Rate g ai/ha	Yield (% vs. Hand Weeding or Untreated Check) Transplanted Rice PRC (1)	Taiwan (3)	Wet Sown Rice PRC (1)	Thailand (2)
Untreated Check	-	-	-	-	100.0 (2.7 MT/ha)
Hand weeding	-	100.0 (6.0 MT/ha)	-	100.0 (5.6 MT/ha)	-
AC 322,140	15	102.5	-	-	-
AC 322,140	20	105.2	-	104.2	142.0
AC 322,140	30	105.6	-	104.7	146.5
AC 322,140	40	106.7	-	104.5	155.5
AC 322,140	60	106.7	-	107.4	153.0
AC 322,140	80	-	-	-	167.0
Bensulfuron	30-45	104.3	-	106.2	147.0
Pyrazosulfuron	15-22.5	104.7	-	104.7	-
Butachlor	1350-1500	104.7	-	-	-
Butachlor (Safened)	750	-	-	-	116.0
Pretilachlor	350-450	-	-	-	122.0
Molinate	3360	-	-	105.1	-

(1) - Yield vs. hand weeding.
(2) - Yield vs. hand weeding.
(3) - Yield not assessed.

Conclusion

The overall results from field trials in the PRC, Taiwan and several South East Asian countries suggest that AC 322,140 is a promising new rice herbicide offering consistent and persistent weed control on a wide range of annual and perennial broadleaf weeds and sedges. Registration of AC 322,140 for use in paddy rice in two to four Far East countries can be anticipated during 1996-1997.

AC 322,140 has the potential to be combined with *E. crusgalli* herbicides. Further field studies and development work are in progress in many Far East countries to explore the tankmix and/or co-formulation potential.

Acknowledgement: The close cooperation of the government agencies in the various Far East countries is greatly appreciated.

References

1. AC 322,140 Experimental Herbicide Product Profile FHT-D302-300-9203. American Cyanamid Company.

2. AC 322,140 Experimental Herbicide Product Profile FHT-D319-800-9311. American Cyanamid Company.

3. AC 322,140: Rice Trial Reports, 1993. Plant Protection Research Institute, Academy of Agri Sciences, Hunan Province.

4. AC 322,140: Rice Trial Reports, 1993. Plant Protection Research Institute, Academy of Agri Sciences, Jilin Province.

5. Murai, S., H. Hasui, K. Kawai, M. Kimpara, and M. Suzuki. 1993. Proc. 14th Asian-Pacific Weed Science Society Conference, Brisbane.

6. Quakenbush, L. S., S. J. Rodaway, B. Tecle, T. E. Brady, B. Lapade, P. Marc, M. E. Condon, and T. Malefyt. 1993. Proc. 14th Asian-Pacific Weed Science Society Conference Brisbane.

7. Wang Huan Min, Li Pu, Wang Xue Wen, S. C. Lee, Zang Xiao Mei, and Ding Hui. 1994. Fifth Weed Science Society Conference, Yunnan, PRC.

8. Limmanee, A., S. Theveethivarak, S. C. Lee, and S. Chinawong. 1994. Thailand National Conference on Weed Science.

RP020630 - A NEW HERBICIDE FOR TRANSPLANTED RICE (*Oryza sativa*)

Y. Oe*, S. Kawaguchi, M. Yokoyama, K. Jikihara
Ami R & D Center, Rhone Poulenc Yuka Agro K. K., 8-3-1 Chuo, Ami, Inashiki
Ibaraki 300-03 Japan

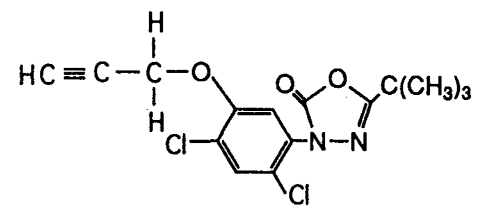
Abstracts RP020630 5-ter-butyl-3(2,4-dichloro-5-propargyloxyphenyl)-1,3,4-oxadiazol-2-(3H)one developed by Rhone Poulenc Agrochimie, was evaluated as a transplanted rice herbicide in Japan in 1994. At the dose rate of 35 - 80g ai/ha, it provided excellent control of *Echinochloa spp.*, annual broad-leaved weeds and *Cyperus difformis* at pre and post emergence application timings. Phytotoxicity in the form of leaf sheath browning was observed at the rate of 120 - 150g ai/ha, but the rice recovered quickly. Mixture with Cumyluron, Daimuron and Bromobutide broadens the weed spectrum. In this paper, herbicidal properties of RP020630 in transplanted rice are reported.

Key wards. RP020630, herbicide, transplanted rice

Introduction
RP020630 5-ter-butyl-3(2,4-dichloro-5-propargyloxyphenyl)-1,3,4-oxadiazol-2-(3H)one is a new experimental herbicide of Rhone-Poulenc Agrochimie. It is a long acting non systemic herbicide that can be used at pre or early post-emergence on rice, sugarcane, turf, non-crop and so on. RP020630 is oxadiazoline new compounds and the same mode of action as Oxadiazon, but it requires a far lower rate. In rice, it can be used with PPI application and post emergence application on transplanted rice, and also used for direct seeded rice.
In Japanese paddy condition RP020630 controls the weed such as *Echinochloa spp., Monochoria vaginalis, Rotale indica, Lindernia procumbens, Cyperus difformis, Alisma canaliculatum, Potamogeton distinctus, Eleocharis acicularis* and *Elatine triandra* with 50~100 gai/ha. This paper presents the basic information on herbicidal activity and rice plants selectivity under greenhouse and field in Japanese paddy condition.

Chemical, physical and toxicological data

common name ; Oxadiargyl
code-number ; RP020630
chemical name ; 5-ter-butyl-3(2,4-dichloro-5-propargyloxyphenyl)-1,3,4-oxadiazol-2-(3H)one
chemical structure ;



appearance ; white powder
melting point ; 134 C
water solubility ; 1 mg/L at 20 C
fish toxicity ; the 96 hour LC50 > water solubility

Material and method

Field trials were made at Akeno, Ami and Ushiku in Ibaraki prefecture in 1994. Weeds were seeded at the depth of 0.5cm into paddy soil. 4 days before transplanting, 3 % of flowable was applied and paddled into the mud at the depth of 3cm uniformly (PPI). Post treatment was also conducted with flowable formulation. After the transplanting the field was submerged to a depth of 2~3 cm and kept the depth. At 21days after application, visual assessment of efficacy and crop damage were made on a scale of 0=(no effect) to 10=(complete kill).

Result and discussion

Herbicidal spectrum

RP020630 showed the high activity against *Echinochloa crus-galli, Monochoria vaginalis, Lindernia procumbens* and *Cyperus difformis* at every treatment timing. However, perennial weeds such as *Sagittaria pygmaea* and *Cyperus serotinus* were not controlled. *Scirpus hotarui* was not killed perfectly, but suppressed the growth with post application.(table1)

Table;1 Herbicidal spectrum at 75gai/ha

weeds	PPI*	Pre**	1.5L***
Echinochloa crus-galli	10	10	10
Scirpus hotarui	4	9	8
Monochoria vaginalis	10	10	9
Lindernia pyxidania	10	10	10
Cyperus difformis	10	10	10
Sagittaria pygmaea	0	1	1
Cyperus serotinus	0	1	0

0~10 efficacy rating system : 0 = no efficacy 10 = complete kill

* : four days before transplanting with PPI

** : application at pre-emergence of ECHCC

*** : application at 1.5L of ECHCC

Activity on the *Echinochloa crus-galli*

The different activity of RP020630 against *Echinochloa crus-galli* was observed at 3 locations. The dose range of > ED95 was between 38 to 75 gai/ha at each location. The reason of different activity is probably due to the organic matter content in soil. Ushiku soil contains 10.0 % of organic matter and Akeno soil contains 5.0 % respectively. And for the Ami soil, sand was added for the improvement of the soil texture, thus, the organic matter content was less, and the efficacy seemed higher. Therefore herbicidal activity of RP020630 is affected by the organic matter content in the soil.(Fig.1)

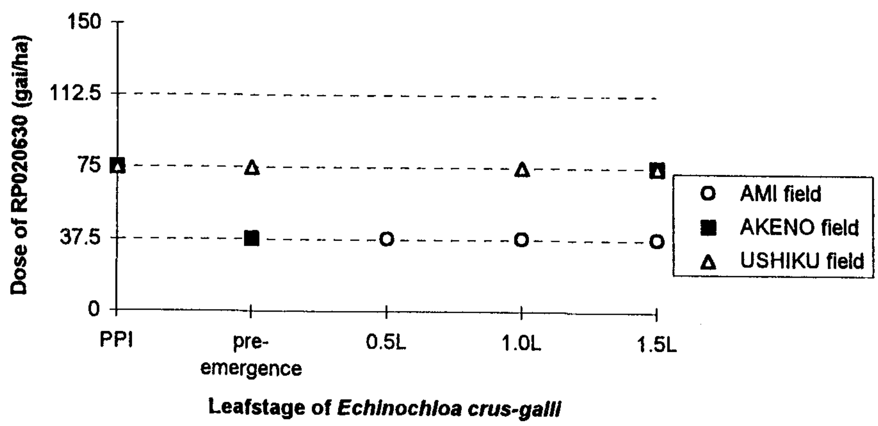


Fig1;Effective dose to control the *Echinochloa crus-galli* in various treatment timings (>ED95)

Selectivity between *Echinochloa crus-galli* and *Oryza sativa*.

Phytotoxicity of RP020630 with both PPI and early post application was observed at the rate of more than 75gai/ha, the symptom was leaf sheath browning, same as that of Oxadiazon. However the phytotoxicity of 75gai/ha was slight and recovered very quickly. At this dose, *Echinochloa* is controlled same as annual dicot weeds and *Cyperus difformis*.(Fig.2)

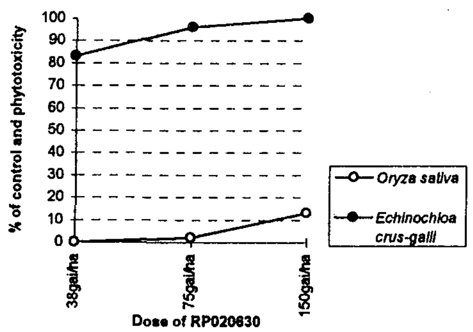


Fig2-1;Selectivity of RP020630 between *Echinochloa crus-galli* and *Oryza sativa* with PPI application

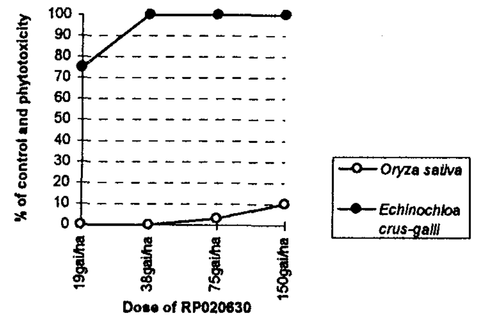


Fig2-2;Selectivity of RP00630 between *Echinochloa crus-galli* and *Oryza sativa* with early post application

Recovery of phytotoxicity

The phytotoxicity of RP020630 with PPI application at the rate of 75gai/ha was very slight, however at the rate of 150gai/ha, the score was more than 10%. This phytotoxicity remained for 21 days after the treatment. After this time, recovery was very quick and at the 35 days assessment, almost no phytotoxicity was observed.

At early post treatment, phytotoxicity was observed at more than 75gai/ha, but the degree of the phytotoxicity was stronger than that of PPI application. The recovery of the phytotoxicity at the rates of 75gai/ha and 150 gai/ha were almost perfect at 35 days after treatment.(Fig.3)

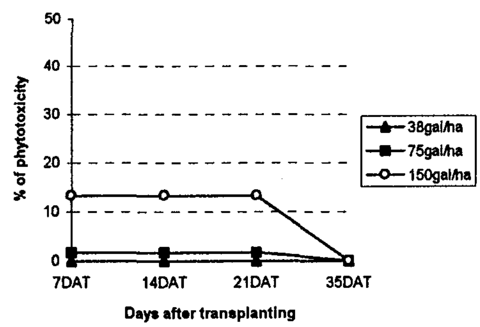


Fig3-1;Transition of recovering the phytotoxicity with PPI application

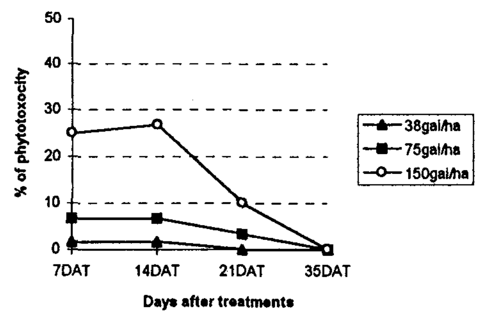


Fig3-2;Transition of recovering the phytotoxicity with early-post application

Persistent period

Persistent period of RP020630 against *Echinochloa oryzicola* was determined in comparison with Oxadiazon in the field condition. At the rate of 150 gai/ha, persistent period was 28 days to 35 days, almost the same as Ronstar (Oxadiazon 600 gai/ha). And at the rate of 75gai/ha, it was 14 to 21 days. (Fig.4)

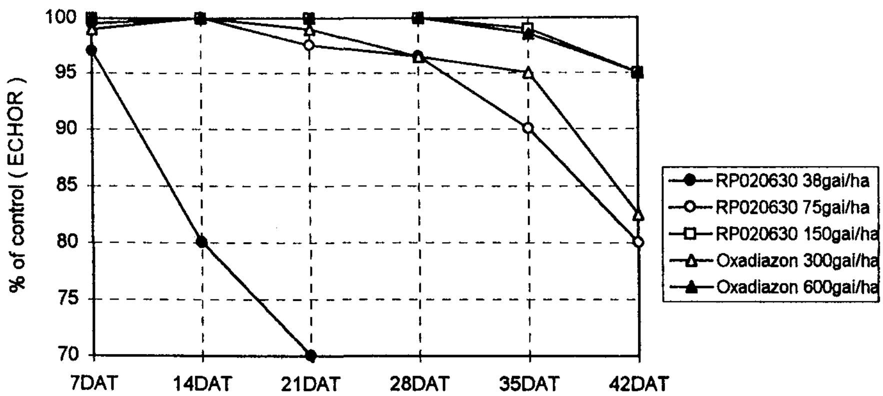


Fig4:Residual activity of RP020630 and Oxadiazon

Combinations

Combination trials were conducted on account of the broader weed spectrum of RP020630. Combinations of RP020630, 60 gai/ha with JC-940 at the rate of 1500 gai/ha, or S-47 at the rate of 1000 gai/ha showed the good control of *Echinochloa oryzicola, Scirpus hotarui,* annual dicot weeds and *Cyperus serotinus.* Also combination with SK-23 at the rate of 2000 gai/ha showed the same performance except the lower activity against *Cyperus serotinus.* In both of PPI and early post application, each combination showed the same spectrum and activity. (table-2)

Table2-1; Effect and phytotoxicity of RP020630 combination at PPI app.

Compounds	App.dose gai/ha	% weed control at 24DAT* *Echinochloa oryzicola*	*Scirpus hotarui*	*Monochoria vaginalis*	*Lindernia pyxidaria*	*Sagittaria pygmaea*	*Cyperus serotinus*
RP020630	60	10	5	10	10	0	2
RP020630+SK-23	60+2000	10	10	10	10	2	7
RP020630+S-47	60+1000	10	10	10	10	3	9
RP020630+JC-940	60+1500	10	10	10	10	3	10
Delcut		10	10	10	10	3	8

Application timing : four days before transplanting (PPI).

0~10 crop injury & efficacy rating system : 0 = no injury or no efficacy 10 = complete kill

* DAT : days after transplanting

Table2-2; Effect and phytotoxicity of RP020630 combination at three days after transplanting app.

Compounds	App.dose gai/ha	% weed control at 21DAT* *Echinochloa oryzicola*	*Scirpus hotarui*	*Monochoria vaginalis*	*Lindernia pyxidaria*	*Sagittaria pygmaea*	*Cyperus serotinus*
RP020630	60	10	9	10	10	0	2
RP020630+SK-23	60+2000	10	10	10	10	0	8
RP020630+S-47	60+1000	10	10	10	10	5	9
RP020630+JC-940	60+1500	10	10	10	10	4	9
Modown (bifenox)		10	9	9	10	6	5

Application timing : three days after transplanting (+3).

0~10 crop injury & efficacy rating system : 0 = no injury or no efficacy 10 = complete kill

* DAT : days after treatment

Conclusion

At extensive field trials in 1994, RP020630 showed the excellent control against *Echinochloa spp.* and annual dicot weeds. The phytotoxicity of RP020630 was observed as the symptom of leaf sheath browning in early stage, however at the rate of less than 75gai/ha, injury was slight and recovered soon. Mixture with JC-940, S-47 and SK-23 showed good complement weed spectrum.

Acknowlegment: We would like to acknowledge to Mr. P.Loubiere of Rhone-Poulenc Agrochimie for giving us technical advice to conduct the trials.

Reference

Kiyochika Hoshikawa ;1989 The growing rice plant an anatomical monograph (published by Nosan gyoson Bunka Kyoukai) p.123~144

HOE 095404 - A NEW SULFONYLUREA-TYPE HERBICIDE FOR THE USE IN RICE

K. Bauer*[1], E. Hacker[1], H. Kehne[1], L. Willms[1], H. Köcher[1], and T. Nakashima[2]

[1] AgrEvo GmbH, Research Frankfurt, D-65926 Frankfurt/Main, Germany
[2] Hoechst Schering AgrEvo K.K., 10 - 33, Akasaka 4-chome, Minato-ko, Tokyo, 107 Japan

Abstract Hoe 095404 (proposed common name: Ethoxysulfuron) is presently being developed by AgrEvo as a herbicide with a wide efficacy spectrum and application window for the control of annual and perennial sedges and dicotyledonous weeds in seeded and transplanted rice. For different uses the product will be available as water dispersible granules (WDG) and granular formulations. The use rates of Hoe 095404 vary between 10 to 60 grams active ingredient per hectare dependent on application method, application timing, growth stages of weeds and weed spectrum to be controlled. The active ingredient inhibits the acetohydroxyacid synthase. It possesses favourable environmental and toxicological properties, such as low mammalian and aquatic toxicity, high soil adsorption and moderate to fast degradation in soil. No negative effects on following rotational crops have been observed so far. Selectivity of Hoe 095404 is due to differential metabolism. For a complete efficacy spectrum Hoe 095404 can be mixed with a range of other rice herbicides. As well as in rice the product can be used selectively for weed control in cereals and sugarcane.

Key words: Ethoxysulfuron, sulfonylurea, ALAC inhibitor, weed control, rice

INTRODUCTION

1. Physical and chemical properties. Hoe 095404 [3-(4,6-dimethoxypyrimidin-2-yl)-1-(2-ethoxy-phenoxysulfonyl)-urea] is a sulfonylurea which has a molecular mass of 398.43 $g \cdot mol^{-1}$. The difference from other rice selective chemicals of this class is due to the oxygen bridge between the aromatic benzene ring and the sulfonylurea moiety. The technical material of Hoe 095404 is a light beige powder with a melting point of 142 - 147 °C. Hoe 095404 is non-volatile (Vapour pressure at 20 °C: $6.6 \cdot 10^{-5}$ Pa = $6.6. \cdot 10^{-7}$ mbar).Octanol/water coefficient, water solubility, Henry's Law constant and hydrolysis are greatly affected by pH (Table 1). The technical material is soluble in dichloromethane and dimethylsulfoxide whereas in other organic solvents and water the solubility is low or moderate.

Table 1. Effect of pH on apparent octanol/water partition coefficient (K_{ow}), water solubility, Henry's Law constant, and hydrolysis of Hoe 095404

	pH			
Parameter	3	5	7	9
Octanol/water partition coefficient at 20 °C[a]	773		1.01	0,06
Water solubility at 20 °C (ppm)[a]		26	1353	9628
Henry's Law constant at 20 °C ($Pa \cdot m^3 \cdot mol^{-1}$)		$1.00 \cdot 10^{-3}$	$1.94 \cdot 10^{-5}$	$2.73 \cdot 10^{-6}$
Hydrolysis in 50 mM phosphate buffer (half-life in days)[b]		65	259	331

[a] K_{OW} and water solubility determination has been carried out using Hoe 095404 technical material of 99.4 % purity by current analytical methodology
[b] Values for hydrolysis half-life at pH 7 and 9 were extrapolated from a 0 to 30 days study

2. Formulation. Hoe 095404 is available as a sprayable formulation in form of water dispersible granules (WDG) containing 150 grams and 600 grams active ingredient per kilogram product, respectively. For granular application the product is available as extruded clay granules. Flowable formulations as well as jumbo granules are under development.

3. Toxicology. As intense testing has shown Hoe 095404 is very safe to mammals and other animal species. The LD_{50} value of the technical product in rats was >5000 mg/kg, the acute dermal LD_{50} in rats was >4000 mg/kg, and the 96-hour LC_{50} in fish (*Brachydanio rerio*) was 320 mg/l. It was not irritating to skin and eyes in rats. There also has been observed no toxic effects on Daphnia, honey bees, and

mallard ducks. In the microbial test Hoe 095404 was non-mutagenic. Long term toxicity studies are being carried out at present.

4. Mode of action. The herbicidal activity of Hoe 095404 in susceptible plants is due to an inhibition of the acetohydroxyacid synthase. Hoe 095404 has an inhibition value (I_{50}) $<10^{-7}$ M.

5. Soil and rotational behaviour. Half-life time for soil degradation under aerobic conditions has been evaluated in a sandy loam soil as DT_{50} = 18 days resulting in a DT_{90} of 58 days. Also under paddy (water logged) conditions Hoe 095404 was rapidly degraded in Japanese soils with half-life times between 10 and <50 days. Model calculations using an intermediate K_{OC} and water solubility near neutral pH indicated no risk for leaching of Hoe 095404 into lower soil levels. Intensive field testing showed that in no case any Hoe 095404 was found below the depth of 20 cm. Biological investigations under field conditions revealed no substantial risk of damage for rotational crops planted after rice growing season and an early application of Hoe 095404 in the recommended dosage rate.

MATERIALS AND METHODS

1. Uptake, distribution, and metabolism studies. Rice (*Oryza sativa*) was grown from seeds, *Cyperus serotinus* from tubers in loamy sand in a greenhouse at 30/19 °C (day/night). The flood water level in the pots was maintained at 2 cm above soil surface. For uptake and distribution studies rice was treated with the ^{14}C-labelled herbicide in the 3- or 4/5-leaf stage, Cyperus serotinus, accordingly, in the 2- or 4-leaf stage. [^{14}C]Hoe 095404 was formulated as WDG and added to the flood water with an initial concentration of 0.2 µg/ml. For degradation studies excised shoots of the test species were placed with the cut end in buffer solution (pH = 6.8) with 7 ppm non-formulated [^{14}C]Hoe 095404. Uptake and distribution of radioactive material in different parts of the test plants was quantified after combustion by liquid scintillation counting. Degradation of [^{14}C]Hoe 095404 was analysed by radio TLC after extraction of the plant tissue with acetone/water (80/20) and phase partitioning at pH 5.0 using methylene chloride.

2. Adsorption/desorption studies. For Hoe 095404 the Freundlich adsorption/desorption studies were determined by using batch slurry method in 5 different soils. The herbicide was evaluated at four concentrations (0.5 - 5 mg/l soil). Freundlich adsorption coefficients (K_f values) were determined for the individual soils and the K_{OC} (soil organic carbon partition coefficient) was calculated by dividing each K_f value by the percentage of organic carbon content of the test soils.

3. Laboratory biotest. Formulated material of Hoe 095404 was incorporated into previously vitalised sandy loam soil using different concentrations of active ingredient. On the day of incorporation and in different time intervals samples were taken from the soil which was kept under constant temperature and humidity. The samples were then deep frozen. Thawing of samples took place at the end of the trial period and the soil was then filled into plastic pots and seeds o) white mustard (*Sinapis alba)* sown on top of the soil and covered by a thin layer of the treated soil. Three weeks after sowing assessment of the biotest was made by visual scoring of the plant damage and determination of fresh weight of test plants.

4. Field testing. Hoe 095404 was intensively field tested in the major rice growing areas world-wide, including East and Southeast Asia, southern Europe, South America and the US. The test method most widely used was plot trials in a randomised block design. Plot size was usually 20 square meters. Trial assessment was done by visual scoring of crop damage and efficacy against weeds.

RESULTS AND DISCUSSION

1. Uptake, distribution, and metabolism of Hoe 095404. One week after application of [^{14}C]Hoe 095404 to the paddy water the concentration of radioactive material in the shoot base of the susceptible weed species *Cyperus serotinus*, which was exposed to the flood water, exceeded the corresponding content in rice by one order of magnitude (640 µg/g fresh weight in *Cyperus serotinus* versus 66 µg/g in rice) (Table 2).

Table 2. Concentration of Hoe 095404-14C equivalents in plant tissue (ng/g plant fresh weight) 7 days after application via paddy water

Plant part	Rice (cv. Binalien)		*Cyperus serotinus*	
	3-leaf stage	4/5-leaf stage	2-leaf stage	4-leaf stage
Shoot above water level	45.5 ± 12.2	26.1 ± 3.2	18.5 ± 5.6	16.7 ± 6.8
Shoot base	178.3 ± 49.5	65.9 ± 21.7	477.6 ± 89.7	640.1 ± 269.8
Root	179.6 ± 48.6	332.6 ± 81.9	160.1 ± 41.0	120.7 ± 48.9
Tuber	-	-	65.3 ± 12.5	109.1 ± 46.9

In both species the concentration of [^{14}C]Hoe 095404 in the shoot above the water level remained markedly lower than in the shoot base and the roots. Degradation to hydrophilic compounds in shoots of rice was more rapid than in shoots of *Cyperus serotinus*. In rice only 7% of the extractable radioactive material was still in the form of the parent compound Hoe 095404 three days after application. After the same time 31% of the herbicide was still detected in *Cyperus serotinus*. These data for the rate of degradation suggest that the selective action of Hoe 095404 is based upon differential degradation in rice and the target weed species. This behaviour is in accordance with observations on other rice selective herbicides (1, 2). In addition, relatively high concentrations of Hoe 095404 in the shoot parts exposed to the treated water-body contribute to the high susceptibility of weed species.

2. Adsorption/desorption studies. The K_{OC} values for Hoe 095404 vary within 57 and 243 dependant on the soil type tested, indicating that Hoe 095404 is bound to soil in a much higher degree than other herbicides used for weed control in rice (i.e. 2,4-D: K_{OC} = 20). Thus the relatively strong adsorption to soil in conjunction with the short half-life of the herbicide results in a minimum liability for leaching of Hoe 095404 to ground water zones.

Table 3. Soil adsorption constants of Hoe 095404 in 4 standard soils and one U.S. soil after a 16 hour adsorption period

	Soil tested				
	SLH	S 2.1	LS 2.2	F 821	Arizona
K_{OC}	57	110	243	81	63
Texture	silt loam	sand	loamy sand	sandy loam	loamy sand
Silt %	70.52	9.07	13.78	18.92	2.84
Sand %	11.46	87.90	85.36	60.05	88.41
Organic matter	1.10	0.92	2.96	1.05	0.16
pH	6.20	5.10	5.50	7.40	8.00

3. Laboratory biotest. Under laboratory conditions Hoe 095404 is readily degraded in biologically active soil. The biological degradation curve suggests a half-life time of about 18 - 20 days for the active ingredient, which is very acceptable for a sulfonylurea type herbicide. Rapid degradation of Hoe 095404 and low susceptibility of rotational crops thus minimise the risk of damage for cultivation species following harvest of the treated rice crop.

4. Field testing. Hoe 095404 controls a wide range of important rice weeds including *Cyperaceae* as well as broad-leaved species (Table 4). Level of activity does not differ significantly regardless of the application method. Optimal application window for the product is the 3 - 4 leaf stage of the target weeds. While efficacy of Hoe 095404 against *Cyperus serotinus* must be regarded as only intermediate to good, grasses like *Echinochloa crus-galli* are not sufficiently controlled by the product.
This means that Hoe 095404 has a high intrinsic selectivity in monocotyledonous plants which is reflected in the extraordinary tolerance of rice against the product (Table 5). Rice tolerance is exceptionally high both in foliar and submerged application, although foliar treatment seems to give even greater selectivity.

Table 4. Field performance of Hoe 095404. Efficacy against major rice weeds at 30 to 60 g a.i./ha and submerged application

	Sensitive	Moderately sensitive	Tolerant
Grasses:			*Echinochloa crus-galli*
Sedges:	*Cyperus difformis*	*Cyperus serotinus*	
	Cyperus iria		
	Eleocharis acicularis		
	Eleocharis kuroguwai		
	Fimbristylis spp.		
	Scirpus juncoides		
Broadleaves:	*Ammania spp.*		
	Lindernia spp.		
	Ludwigia spp.		
	Monochoria vaginalis		
	Rotala indica		
	Sagittaria trifolia		
	Sagittaria pygmaea		
Application window:	2 - 4 leaves of weeds		

Table 5. Field performance of Hoe 095404. Crop tolerance at 15 - 60 g a.i./ha

Parameter	Crop tolerance
Transplanted rice	
submerged application - granules	tolerated
foliar/spray application - wettable powder	tolerated
Varieties	No response
Direct seeded rice / water seeded rice	
submerged application	tolerated
foliar/spray application	tolerated
Varieties	No response

Hoe 095404, thus, provides an excellent tool for weed management in transplanted and water-seeded rice (see also 3, 4). Its very low level of animal and environmental toxicity is combined with low soil mobility and excellent weed control rates in conjunction with high rice selectivity. For completion of the efficacy spectrum Hoe 095404 may be mixed with other rice herbicides such as Anilofos, Benfuresate etc. (3). The new herbicide has also shown interesting activity and selectivity in cereals and sugarcane.

ACKNOWLEDGMENTS

The authors wish to thank colleagues from environmental sciences as well as from toxicological department, Dr. Schollmeier and Dr. Ehling in particular, for their kind support and contribution to this presentation.

REFERENCES

1. Beyer E. M., M. J. Duffy, J. V. Hay, and D. D. Schlueter, 1987, Sulfonylurea herbicides, Ed.: P. G. Kearney and D. D. Kaufmann, New York
2. Brown H. M. , 1990, Mode of action, crop selectivity, and soil relations of the sulfonylurea herbicides, Pest. Science, 29, 263 - 281
3. Nakajima T., N. Chiba, and H. Schubert, 1995, Hoe 095404, A novel herbicide for use in Japanese paddy rice cultivation, Proc. 15th Asian Pacific Weed Sci. Soc, in press
4. Sitchawat T., and S. Khattiyakarun., 1995, Hoe 095404, a novel herbicide controlling braodleaves and sedges alone or in combination with grass herbicides by one-shot application in direct seeded rice in Thailand, Proc. 15th Asian Pacific Weed Sci. Soc, in press

Hoe 95404 a New Herbicide Controlling Broadleaf's and Sedges in Direct Seeded Rice in Thailand

T. Sitchawat* and S. Khattiyakarun
Hoechst Schering AgrEvo (Thai) Ltd., PO Box 130, Yannawa, Bangkok 10120, Thailand

Abstract. Hoe 95404 is a sulfonylurea herbicide for broadleaf and sedge control developed by Hoechst Schering AgrEvo GmbH, Germany. Its efficacy was tested against major broadleaf's and sedges i.e. *Sphenoclea zeylanica, Monochoria vaginalis, Jussiaea angustifolia, Cyperus difformis* and *Fimbristylis miliacea* in direct seeded rice in 1990. At 21 to 28 days after seeding (DAS), Hoe 95404 and metsulfuron methyl at 20 and 6 g.ai/ha, respectively, gave excellent control, except *F. miliacea* which was completely controlled by Hoe 95404 but not controlled by metsulfuron methyl at 28 days after application . To improve its weed spectrum, tank-mixtures of Hoe 95404 plus grass herbicides at various rates and timing for one-shot control of the mentioned broadleaf's and sedges plus *Echinochloa crusgalli* and *Leptochloa chinensis* were tested in 1991-1992. Hoe 95404 plus thiobencarb and Hoe 95404 plus butachlor at 7.5+2,000 and 7.5+750 g.ai/ha, respectively, applied at 5 DAS gave better overall control than Hoe 95404 plus propanil at 7.5+2,000 and thiobencarb/propanil at 1,333.3/666.7 g.ai/ha (recommended rate). At 10 DAS, Hoe 95404 plus propanil at 10+2,000 g.ai/ha showed better overall control than thiobencarb/propanil 1,333/666.7 , Hoe 95404 plus thiobencarb at 10+2,000 and Hoe 95404 plus butachlor at 10+750 g.ai/ha. In defining the rate of application and its flexibility, Hoe 95404 plus propanil at 15+1,500 at either 10 or 15 DAS gave better overall control than Hoe 95404 plus thiobencarb at 10+1,500 at 10 DAS, thiobencarb/propanil at 1,333.3/666.7 and butachlor/propanil at 722/722 g.ai/ha (recommended rate). Yields from each treatment were significantly higher than untreated control.

Key Words. sulfonylurea, single application, direct seeded rice, early to mid post emergence, combinations

INTRODUCTION

Pre-germinated direct seeded rice is the most popular rice cultivation method for the important rice production areas in Thailand. Weed problems in this kind of cultivation are always quite serious. There are many different weed types found in the pre-germinated direct seeded rice. Vongsaroj (1984) reported that *Echinochloa crusgalli* was the most dominant of the grasses, *Sphenoclea zeylanica* of broadleaf weeds, *Cyperus difformis* of sedges and *Marsilea crenata* of ferns, respectively (1).

At the present time there are many kinds of herbicides recommended for use in rice depending on weed species and timing of application. For pre- to early-post-emergence, pretilachlor, thiobencarb, thiobencarb/propanil, butachlor, butachlor/propanil, etc. are recommended. While propanil, fenoxaprop-P-ethyl, 2,4-D, metsulfuron methyl and chlorimuron ethyl, etc. are recommended for mid- to late post-emergence. As mentioned, these herbicides are appropriate and effective for certain groups of weeds due to their chemical nature. For instance pretilachlor, butachlor, thiobencarb and propanil are very effective against most of the grasses and also some broadleaf's and sedges. On the other hand, 2,4-D, metsulfuron-methyl and chlorimuron-ethyl are found to give good control of most broadleaf's and sedges (2).

Hoe 95404 is a new sulfonylurea being developed by Hoechst Schering AgrEvo GmbH. The product is preliminary reported to be very effective against a wide range of broadleaf's and sedges with good crop safety in rice and cereals. To get an appropriate recommendation for using in pre-germinated direct seeded rice in Thailand, the experiments were carried out both as a single product and in tank-mixing with certain grass-dominant herbicides for one-shot weed control particularly at early to mid post emergence.

MATERIALS and METHODS

The experiments were conducted in Supanburi province during 1990-1992. Each experiment was RCB designed with 4 replications. RD23 rice variety was sown in 4 x 4 m. plots. Herbicide applications were applied by a conventional knapsack fitted with a Tee-jet nozzle at a spray volume of 500 l/ha. The water in the field was drained out before herbicide application, and 3 days later was re-irrigated to 5 cm depth. Weed control efficacy and rice phytotoxicity were assessed by visual rating based on 0-100%, whereas 0 and 100 represented no weed and complete weed control, and no crop injury and complete crop destruction, respectively. Rates of application expressed in g./ha throughout the paper are meant as g.ai/ha.

Experiment 1
At Supanburi (Sept.-Dec.1990), Hoe 95404 at 20 g./ha was compared to metsulfuron methyl at 6 g./ha against common broadleaf's i.e. *Sphenoclea zeylanica, Monochoria vaginalis, Jussiaea angustifolia* and sedges i.e. *Cyperus difformis* and *Fimbristylis miliacea.* Each treatment was applied at 21, 28 and 35 days after rice seed sowing (DAS). Percent weed control and crop phytotoxicity were assessed at 7,14,21 and 28 days after the application.

Experiment 2
At Supanburi (Mar.-July, 1991), Hoe 95404 at 7.5 and 10 g./ha were tested at 5 and 10 DAS. The mixing partners were thiobencarb 2,000, butachlor 750 and propanil 2,000 g./ha. The combinations were compared to thiobencarb/propanil at 1,333.3/666.7 g./ha and the untreated. The assessment of weed control and crop phytotoxicity was the same as in experiment 1. Rice yields were also evaluated.

Experiment 3
At Supanburi (Dec.1991-April 1992), Hoe 95404 at 10 and 15 g./ha were tested at 5,10 and 15 DAS. Its mixing partners were propanil and thiobencarb each at 1,500 g./ha. The said mixtures were compared to thiobencarb/propanil and butachlor/propanil at 1,333.3/666.7 and 722/722 g./ha, respectively. The assessment was the same as in experiment 1. Rice yields were evaluated.

RESULTS AND DISCUSSION

Experiment 1
The major weeds infesting at the Supanburi rice field are *Sphenoclea zeylanica, Monochoria vaginalis, Jussiaea angustifolia, Cyperus difformis* and *Fimbristylis miliacea.* The efficacy of Hoe 95404 at 20 g./ha for total broadleaf and sedge control was in the same level as metsulfuron methyl at 6 g./ha at the corresponding application timing except that the latter gave no control for *F. miliacea.* Hoe 95404 applied at 21 and 28 DAS gave excellent control on the mentioned weeds but at 35 DAS, its efficacy dropped from 98 and 95 to 89%. Declining of percent control mainly attributed to no control on *J. angustifolia* at very late application. No phytotoxicity on rice was found in any treatment (Table 1).

Table 1: Efficacy of Hoe 95404 for broadleaf weed and sedge control in direct seeded rice at Supanburi, Thailand, September - December 1990 [a]

Treatments	Rate (g.ai/ha)	Appl. timing DAS [c]	% Weed control [b] at 28 DAA [c] T [c]	S	M	J	C	F
Hoe 95404	20	21	98	100	100	100	100	100
Hoe 95404	20	28	95	100	100	78	100	100
Hoe 95404	20	35	89	100	93	0	98	98
Metsulfuron methy	6	21	96	100	100	100	100	0
Metsulfuron methyl	6	28	99	100	100	100	100	0
Metsulfuron methyl	6	35	89	99	100	90	94	0
Untreated	-	-	(40)[d]	(7)	(11)	(9)	(6)	(5)

[a] Herbicides were applied by a knapsack sprayer at spray volume of 500 l/ha.
[b] Assessment by visual rating based on 100% scale, while zero and 100 represented no crop injury and complete crop injury and no weed control and complete weed control, respectively.
[c] DAA = days after application, S = *Sphenoclea zeylanica*, M = *Monochoria vaginalis*, J = *Jussiaea angustifolia*, C = *Cyperus difformis* and F = *Fimbristylis miliacea*
[d] Present % weed coverage

Experiment 2
The major weeds in this experiment were *E. crusgalli, Leptochloa chinensis, S. zeylanica, C. difformis* and *F. miliacea.* Application at 5 DAS, Hoe 95404 tank-mixed with either thiobencarb or butachlor could improve grassy weed control of Hoe 95404. Each of its combinations with thiobencarb and butachlor at 7.5+2,000 and 7.5+750 g./ha gave 93 and 90% total weed control and 88 and 76% on grasses, respectively. The efficacy of the afore-mentioned treatments were better than the standard - thiobencarb/propanil. Hoe 95404 in mixture with propanil at 7.5+2,000 g./ha, on the other hand gave only 48% total weed control but without grass control action. The weakness on grass control may be attributed to the critical timing of application. Since propanil is a post-emergent herbicide with no soil residual activity, but when applied at 5 DAS some of the weeds have not yet emerged. In fact, either Hoe 95404 + propanil or thiobencarb/propanil gave a satisfactory grassy weed control at 28 DAA with 90 and 95% respectively. The harvested yields reflected and corresponded to the level of weed control of each herbicide. Phytotoxicity caused by the combination of Hoe 95404 with butachlor, and propanil, and including the standard herbicide, did not affect to the yield. Yields from each treatment were significantly higher than untreated control (Table 2).

Table 2: Efficacy of Hoe 95404 plus other grass herbicides for one shot weed control in direct seeded rice at Supanburi, Thailand, March - July 1991 [a]

Treatments	Rate (g.ai/ha)	% Phytotoxicity [b] 7	14 DAA [c]	% Weed control [b] at 56 DAA [c] T [c]	G [e]	B	S	Yield [f] (kg/ha)
5 DAS								
Hoe 404+thioben	7.5+2,000	0	0	93	88	84	100	4,266wx
Hoe 404+butach.	7.5+750	10	0	90	76	82	99	4,672wx
Hoe 404+propanil	7.5+2,000	28	10	48	0	66	100	3,766 xy
Thioben./propanil	1333.3/666.7	21	10	38	58	0	100	3,094 y
Hand-weeded at 33 DAS	-	0	0	81	98	83	73	3,219 xy
Untreated	-	0	0	(96)	(21)	(22)	(52)	625 z
10 DAS								
Hoe 404+thioben.	0+2,000	0	0	70	8	93	100	4,734wx
Hoe 404+butach.	10+750	10	0	63	6	90	97	4,531wx
Hoe 404+propanil	10+2,000	30	16	81	48	74	100	4,453wxy
Thioben./propanil	1333.3/666.7	26	11	41	25	10	81	3,391 xy
Hand-weeded at 33 DAS	-	0	0	85	97	83	81	3,703 xy
Untreated	-	0	0	(90)[d]	(18)	(25)	(46)	1,344 z

[a,b,c,d] = See Table 1
[e] = G = grasses; *Echinochloa crusgalli, Leptochloa chinensis,*
B = *broadleaf's; S. zeylanica*
S = sedges; *C. difformis, F. miliacea*
[f] = means followed by the same letters are not significant from each other according to DMRT at P = 0.052

At 10 DAS, Hoe 95404 mixed with propanil at 10+2,000 g./ha has improved grass control to 48% while Hoe 95404 combined with thiobencarb or butachlor showed very low control on grasses. At 56 DAA, the long lasting control on broadleaf's and sedges of Hoe 95404 plus either thiobencarb or butachlor was the major factor to provide more space for a more competitive grass species to germinate. Nevertheless, % control on total weed broadleaf's and sedges in each of the mentioned combination was higher than thiobencarb/propanil at 1,333.3/666.7 g./ha. Yield from each treatment was not affected by the level of phytotoxicity and was significantly higher than untreated control.

Experiment 3
At 56 DAA, most of the weed coverage was grasses, followed by broadleaf's and sedges. Hoe 95404 plus propanil at 15+1,500 g./ha was the best combination for overall weed control ranging from 92-95% when applied at 10-15 DAS. Second rank for overall weed control was achieved by Hoe 95404+thiobencarb applied at 5-10 DAS and ranged from 87-94%. Equal or slightly inferior was

thiobencarb/propanil at 1,333.3/666.7 applied at 5 DAS and butachlor/propanil at 722/722 g./ha applied at 10 DAS. Phytotoxicity of the mixture of Hoe 95404+propanil at the level of 11-13% from 7-14 DAA did not have any effect on yield. Yield from each treated plot was significantly higher than untreated control (Table 3).

Table 3: Efficacy of Hoe 95404 plus some herbicides for one shot weed control in direct seeded rice at Supanburi, Thailand, December 1991 - April 1992 [a]

Treatments	Rate	Ap.timing	% Phytotoxic [b]		% Weed control [b] at 56 DAA [c]				Yield [f]
	(g.ai/ha)	DAS [c]	7	14DAA [c]	T [c]	G [e]	B	S	(kg/ha)
Hoe404+thioben.	10+1,500	5	0	0	94	82	100	100	4,422x
Hoe404+thioben.	10+1,500	10	0	0	87	63	100	100	4,031x
Hoe404+thioben.	15+1,500	10	13	0	92	97	100	100	4,360x
Hoe404+propanil	15+1,500	15	11	3	95	86	100	100	4,766x
Thioben./propanil	1333.3/666.7	5	11	0	88	95	90	80	5,016x
Butachlor/propanil	722/722	10	14	3	87	92	70	100	4,875x
Hand-weeded at 35 DAS	-	35	0	0	86	92	100	25	4,797x
Untreated	-	0	0	0	(50)[d]	(36)	(10)	(4)	2,375 y

a,b,c,d,e,f = See Table 2

As a single product, Hoe 95404 proved to be a very valuable and reliable compound for broadleaf weed and sedge control. In combination with grass active materials, it will allow excellent broad spectrum weed control as a one shot application.

ACKNOWLEDGEMENTS: The authors wish to acknowledge the contribution of Dr.Weerawooth Katanyukul and Mr.Wichit Chomsuk for their contribution toward these studies while they were with Hoechst Thai Ltd. They also wish to express their thanks and appreciation to Mr.Andrew McDowell for his kind support and help in preparing this manuscript.

REFERENCES

1. Vongsaroj, P. 1984. Proc. 1st Tropical Weed Sci. Conf., Bangkok. pp 297-307.
2. Weed Science Society of Thailand 1993. Weed control guideline (Thai version). WSST, 1st ed. Bangkok. pp 8-21.

Hoe 095404, A Novel Herbicide For Use in Japanese Paddy Rice Cultivation

T. Nakajima, N. Chiba, H. Schubert

Hoechst Schering AgrEvo K.K., Japan

ABSTRACT. Hoe 095404 (proposed common name: ethoxysulfuron) is a novel herbicide possessing high herbicidal activity against a broad range of weed species with excellent selectivity in rice. This compound is very active at low rates, (10 ~ 30 g a.i. /ha) on important sedge and broadleaf weed species and is flexible with respect to application timing. Hoe 095404 provides outstanding residual activity against annual broadleaf weed species like *Monochoria vaginalis* by submerged application. In Japan the compound has been developed mainly as a component for one shot treatment herbicides in combinations with supplementary compounds. During the last few years several combination products containing Hoe 095404 have been created and tested under practical field conditions at Hoechst Schering AgrEvo KK Agricultural Research Center in Naruto, Chiba-ken and in official experimental sites. It has been confirmed that Hoe 095404 possesses high potential as a component for controlling sedge and broadleaf weed species with excellent residual activity, particularly as a component for one shot treatment herbicides.

Key words Hoe 095404, sulfonylurea, paddy rice herbicide, herbicidal properties, benfuresate

INTRODUCTION

Hoe 095404 has been discovered by Hoechst as a herbicide and was subsequently tested in rice and other crops world wide [1 2]. In Japan Hoe 095404 has been developed under the local code number Hoe-404 as a component mainly for one shot treatment herbicides in rice in combination with supplementary compounds. In one shot treatment herbicides, the rate of Hoe 095404 has been set at 21 g a.i./ha. This paper describes the properties of Hoe 095404 as a herbicide component for rice cultivation in Japan.

MATERIALS AND METHODS

1. Herbicidal spectrum of Hoe 095404 under field conditions

A field test was conducted in Naruto, Chiba-ken, Japan in order to determine the herbicidal spectrum of Hoe 095404. Soil type of the test field was loam and there was a high infestation with *Monochoria vaginalis* (more than 1000 plants/m^2 in untreated plots). Rice plants (cv. Nihonbare) were transplanted and Hoe 095404 granule formulation was applied to the paddy water. Herbicidal performance was assessed 56 days after application while crop safety was evaluated at 14 and 28 days after treatment.

2. Herbicidal activity against annual broad leaf weeds

In a greenhouse test Hoe 095404 (WP) was applied to the submerged paddy water in pots when *Monochoria vaginalis*, *Lindernia procumbens* and *Rotala indica* were in the pre emergent stage. Herbicidal activity was evaluated 40 days after application.

3. Residual activity

Hoe 095404 (WP) was applied to pots filled with clay loam paddy soil. At different time intervals after the application seeds of *Monochoria vaginalis* as an indicator plant were sown. Residual activity was evaluated by comparing herbicidal activity after 6 weeks of each sowing time with that of the untreated pot.

4. Influence of leaching on herbicidal activity

In the greenhouse, leaching influence on herbicidal activity was investigated with *Sagittaria pygmaea* as a test plant. Clay loam paddy soil was filled into pots (500 cm^2). After puddling, tubers of *Sagittaria pygmaea* were transplanted and a suspension of Hoe 095404 WP was applied to paddy water after the weed reached the 0.5 leaf stage. Leaching conditions were imitated by eluting the soil column with 2 cm of water/day for 3 days, starting 24 hr after application. The herbicidal activity was evaluated 8 weeks after application.

5. Influence of overflow on herbicidal activity

Monochoria vaginalis was used as a test plant. Under greenhouse conditions, clay loam paddy soil was filled into a pot (200 cm^2) and - after puddling-seeds of *Monochoria vaginalis* were sown onto the soil. A suspension of Hoe 095404 WP was applied to the paddy water (4 cm depth) at the pre emergence and - in a parallel trial - at the 0.5 leaf stage of the weed. 24 hours after the treatment 75% (3 cm) of the supernatant water were replaced by fresh water. This procedure was repeated three more times at an interval of 24 hours, herbicidal activity was assessed 65 days after each application.

6. Influence of leaching on crop safety

Hoe 095404 was evaluated on its crop safety under leaching and under standard conditions with a pot (200 cm^2) experiment in the greenhouse. Japonica type of rice (cv.: Nihonbare) was transplanted at 2 cm depth into paddy soil (clay loam) after puddling. A suspension of Hoe 095404 (WP) was applied 5 days after transplanting. The leaching process was conducted with 3 cm / day for 2 days, starting 24 h after application. Crop safety was evaluated visually 23 days after application.

7. Influence of temperature on crop safety

A growth chamber test was carried out. Pots filled with light clay paddy soil were placed in two different growth chambers with temperature and relative humidity adjusted at 23 / 19 °C, 70/90% and 30/26 °C, 70/90% (day / night), respectively. Rice plants (cv. Nihonbare) were transplanted and a suspension of Hoe 095404 (WP) was applied 4 days after transplanting. By recording fresh weight of rice plant shoots, crop safety of Hoe 095404 was evaluated.

8. Interaction between Hoe 095404 and benfuresate

Seeds of *Scirpus juncoides* were sown onto the soil (clay loam) after puddling. Chemical suspensions of the tested products were applied to the paddy water when *Scirpus juncoides* was in the beginning of emergence. Herbicidal activity was assessed visually 59 days after application.

From the obtained results, the expected herbicidal activity of the combinations was calculated with Colby Formula [3]. The calculated value and the actual herbicidal activity were plotted on the graph which X and Y axis show the herbicidal activity (%) of Hoe 095404 and the expected value (E) or the actual herbicidal activity of the combinations, respectively.

RESULTS AND DISCUSSION

1 Herbicidal spectrum of Hoe 095404 in the field

Hoe 095404 at 21 g a.i./ha provided excellent herbicidal performance against annual and perennial sedge and broadleaf weed species with high crop safety at both application times (1.0 and 2.0 leaf stage of *Echinochlas crus-galli* as a indicator for weed stage) (Table 1). The compound in particular had excellent residual activity against *Monochoria vaginalis* which infestation was extremely high and emergence period was very long at this test. *Echinochloa crus-galli* was the only species in this trial which had a low susceptibility to Hoe 095404.

Table 1. Herbicidal spectrum of Hoe 095404, 21 g a.i./ha

Application time	Herbicidal activity (%)[1]								Crop injury (%)[2]	
	E.c.	C.d.	M.v.	L.p.	R.i.	S.j.	C.s.	S.p.	14DAA	28DAA
+ 3 Days after transplanting (~1.0 leaf stage of E.c.)	30	100	100	100	100	95	90	90	3	0
+6 Days after transplanting (~2.0 leaf stage of E.c.)	10	100	100	100	100	100	90	98	0	0

1) Herbicidal activity (%): 0 ~ 100: No effect ~ Completely controlled
- E.c: *Echinochloa crus-galli*
- C.d.: *Cyperus difformis*
- M.v.: *Monochoria vaginalis*
- L.p.: *Lindernia procumbens*
- R.i.: *Rotala indica*
- S.j: *Scirpus juncoides*
- C.s.: *Cyperus serotinus*
- S.p.: *Sagittaria pygmaea*

2) Crop injury (%): 0 ~ 100: No effect ~ Completely killed
DAA: Days after application

2. Herbicidal activity against annual broad leaf weeds

The annual broadleaf weed species tested were extremely susceptible to Hoe 095404 (Fig. 1). ED_{80} value were in the range of 0.5 ~ 1.0 g a.i./ha, 0.5 ~ 1.0 g a.i./ha and 1.0 ~ 2.0 g a.i./ha for *Monochoria vaginalis*, *Lindernia procumbens*and *Rotala indica,* respectively.

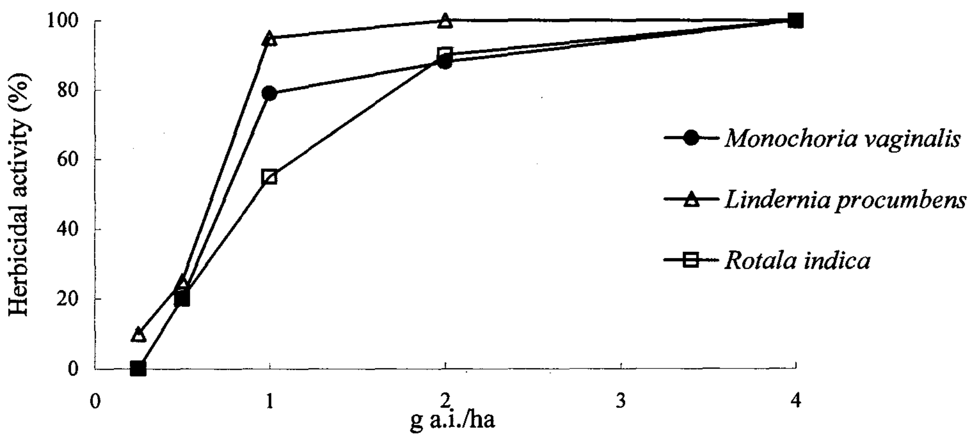


Fig. 1 Herbicidal activity of Hoe 095404 against annual broadleaf weeds

3 Residual activity

Hoe 095404 gave outstanding residual activity against *Monochoria vaginalis* even at 5 ~ 10 g a.i./ha which is one half to one quarter of the target rate for one shot treatment herbicides (Fig. 2).

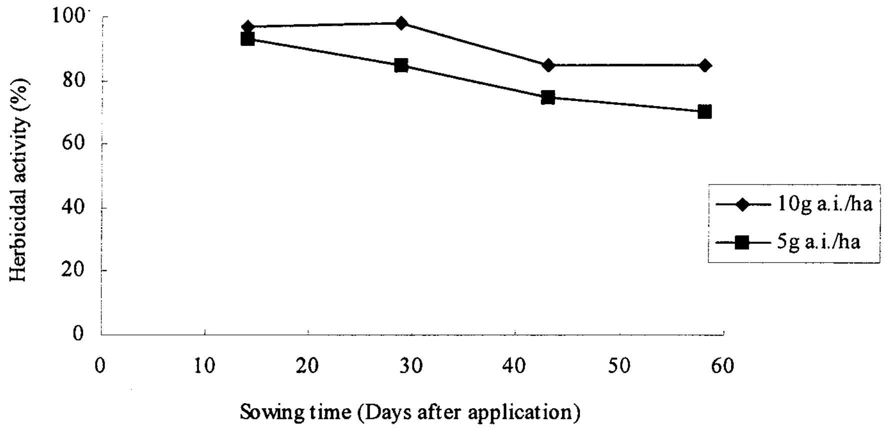


Fig. 2 Residual activity of Hoe 095404 against *Monochoria vaginalis*

4 Influence of leaching on herbicidal activity

There was no remarkable difference in herbicidal activity between the trials conducted under leaching and standard conditions (Fig. 3). Leaching is therefore not expected to significantly influence the herbicidal performance of Hoe 095404 on *Sagittaria pygmaea*.

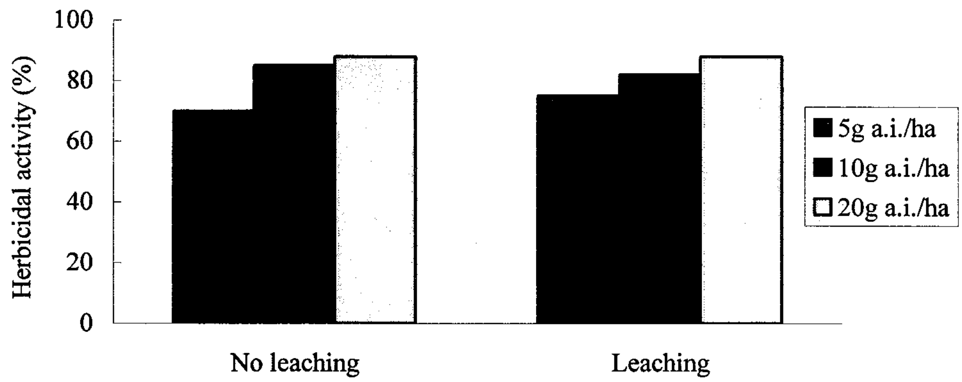


Fig.3 Influence of leaching on herbicidal activity of Hoe 095404 on *Sagittaria pygmaea*

5 Influence of overflow on herbicidal activity

The efficacy of Hoe 095404 was not affected by a simulated overflow (Table 2). This result suggests that the herbicidal activity of Hoe 095404 on *Monochoria vaginalis* could be expected to be stable even in case overflow of the paddy field occurs due to rainfall.

Table 2. Influence of overflow on herbicidal activity (21 g a.i./ha)

Application time	Herbicidal activity(%)	
	No draining	Draining
Pre emergence	100	100
0.5 leaf stage	100	100

6 Influence of leaching on crop safety

Hoe 095404 did not cause any crop injury at 21 g a.i./ha under leaching and no leaching conditions (Fig. 4). Slight crop injury (10 %) was observed only at 42 g a.i./ha under leaching condition. However, this crop injury completely recovered one month after application. Leaching could be the factor to differ the crop safety of Hoe 095404.

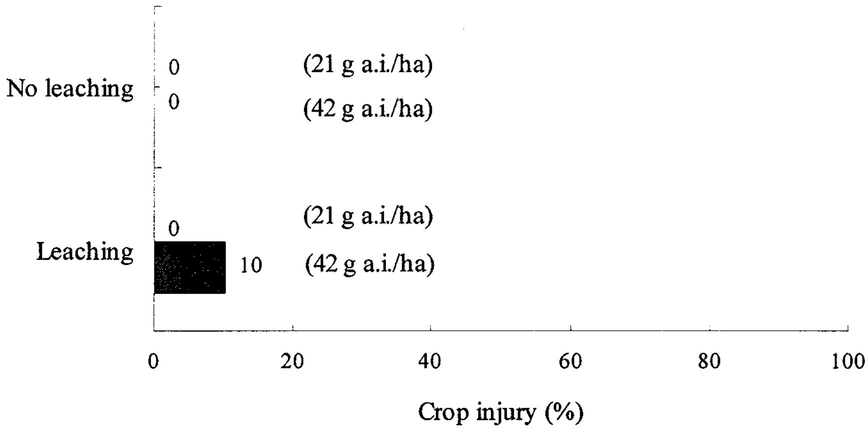


Fig. 4 Influence of leaching on crop safety of Hoe 095404

7 Influence of temperature on crop safety

Hoe 095404 was very safe even under high temperature conditions.

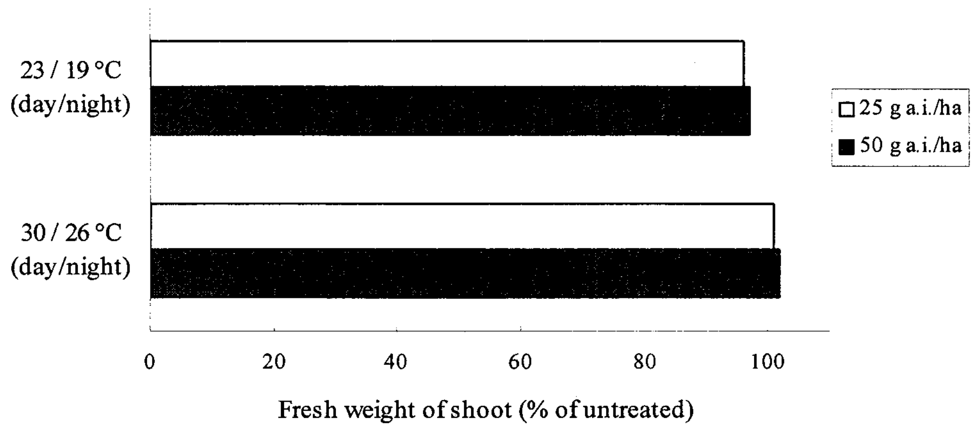


Fig. 5 Influence of temperature on crop safety to transplanted paddy rice

8 Interaction between Hoe 095404 and benfuresate

By comparing the mixture's actual herbicidal activity with the corresponding values calculated (Colby Formula) from the performance of its single components, a clear synergism between the two active ingredients on *Scirpus juncoides* can be derived.

Table 3 Interaction between Hoe 095404 and benfuresate on *Scirpus juncoides*

Compound		Rate (g a.i./ha)	Herbicidal activity (%)
Hoe 095404		5	30
		10	70
		20	85
benfuresate		150	70
Hoe 095404	+ benfuresate	5 + 150	95
		10 + 150	100
		20 + 150	100

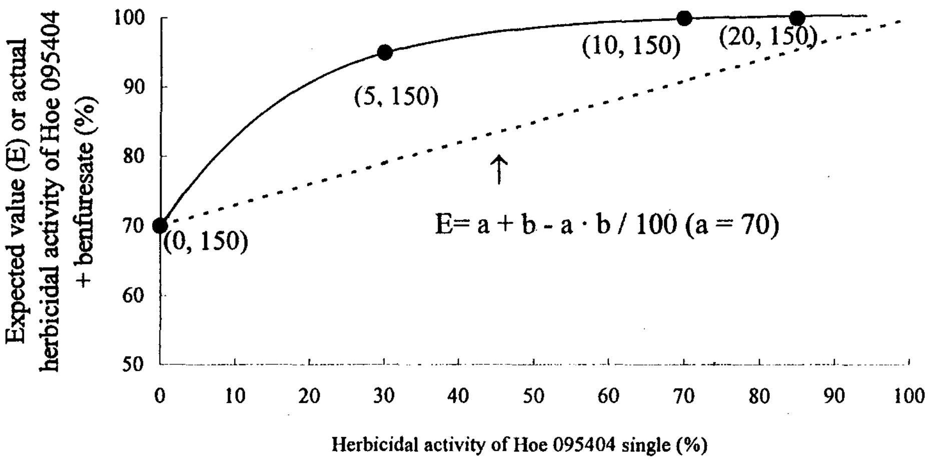


Fig. 6 Interaction in herbicidal activity between Hoe 095404 and benfuresate on *Scirpus juncoides*

- - - - - - : Calculated activity E= a + b - a · b / 100 (a = 70)
E: Expected value
a: Herbicidal activity (%) of benfuresate at 150 g a.i./ha
b: Herbicidal activity (%) of Hoe 095404

——●—— : Actual activity of the mixture
( ): (Rate of Hoe 095404, Rate of benfuresate)

In view of all results shown above, Hoe 095404 has to be seen as an outstanding rice herbicide component for paddy rice cultivation in Japan. Its strong points include:

1. Broad spectrum (Active on annual / perennial sedge and broad leaf weed species)
2. Excellent residual activity against annual broad leaf weed species like *Monochoria vaginalis*
3. Stable herbicidal activity under conditions of leaching and overflow
4. High crop safety to transplanted paddy rice
5. Good crop safety even at higher temperatures
6. Synergism with benfuresate on sedge species

REFERENCE

1. K. Bauer et al. 1995
Hoe 095404 - A new sulfonylurea - type herbicide for the use in rice
Proc. 15th Asian Pacific Weed Sci. Soc., 1995, in press

2. S. Tawatchai et al. 1995
Hoe 095404, a novel herbicide controlling broadleaves, sedges alone or in combination with grass herbicides as one-shot application in direct seeded rice in Thailand
Proc. 15th Asian Pacific Weed Sci. Soc., 1995 in press

3. Colby, S. R. 1967
Calculating synergistic and antagonistic response of herbicide combinations
Weeds **15** (1), 20-22

CYHALOFOP BUTYL, A SELECTIVE POSTEMERGENT GRAMINICIDE FOR USE IN DIRECT SEEDED RICE IN ASIA

N.S. Mendoza[1], A.B. Tambi[2] and P. Dryden[3]

[1]DowElanco Philippines, 6750 Ayala Metro Manila, Philippines
[2]DowElanco (M) Sdn Bhd, Jalan Keluli 15/16, section 15, 40200 Shah Alam, Selangor, Malaysia
[3]DowElanco Pacific Ltd., Wanchai, Hong Kong

Abstract. Cyhalofop butyl was field evaluated in three Asian countries from 1992 to 1994 to determine its activity on a range of grass weeds in paddy rice. Studies were designed to determine: optimum dose rates; effect of adjuvant; rice selectivity; application timing and performance under different paddy water regimes. Cyhalofop butyl was tested at rates of 30-240 g a.i./ha against various growth stages of Echinochloa spp and Leptochloa chinensis. It was found active on grasses at all stages from 2 leaf stage to early tillering. Targeting grasses in the 3 to 4 leaf stage, optimum use rate (GR90) was in the range of 120 - 240 g a.i./ha. However, the addition of an adjuvant, Polyglycol 26-2 (PG 26-2) at 0.1 to 0.4% v/v, markedly enhanced its activity. Optimum use rate was in the range of 30-80 g a.i./ha with 0.2% v/v PG 26-2. Good activity on these grass weeds was maintained under different paddy water levels provided that grass weeds were well exposed to the herbicide. At all application timings, in direct seeded indica rice, cyhalofop butyl was completely selective at the highest rate tested.

Introduction

Direct seeding or wet seeding paddy rice culture is increasing in the ASEAN countries. Reduced labor costs associated with this method of growing rice and a shortage of farm labor brought about by industrialization in these countries are the reasons farmers have readily adopted this method of planting. (Smith and Shaw, 1966; Bernasor and De Datta, 1983). Compared to transplanted rice culture, weed control is more critical in direct seeded rice as weeds emerge and grow almost simultaneously with the rice crop. Under these condition, proper application of herbicide to control weeds is a must.

Almost all herbicides registered and use for weed control in direct seeded rice in Asia are applied pre-emergent. They have a narrow application window and render the herbicide application schedule less flexible. DowElanco's cyhalofop butyl (XDE-537, DEH-112), (R) butyl-2-(4-(4-cyano-2-fluorophenoxy) phenoxy) propionate, is a new post-emergent graminicide with a wide application window. To assess this product for use in direct seeded paddy rice, field studies were conducted to determine; optimum dose rates, effect of adjuvants, rice selectivity, application timing, and performance under different paddy water regime.

Materials and Methods

Field trials were conducted in the Philippines, Malaysia, and India. Treatments and rates of application for each study are presented in Table 1, 2, and 3.

The experimental plots (20 square meters) were surrounded with levees 25 cm in width and height. Irrigation and drainage canals were established so plots could be irrigated and drained independently, without interplot contamination. In studies that assessed optimum dose rates, effect of adjuvants and selectivity, plots were laid out following randomized complete block design. Split plot design was used for studies that evaluated performance under different paddy water regimes as well as dose rate, rate of adjuvants and application timing.

Indica rice varieties were used in all studies. Pre-germinated rice seeds were broadcast manually onto the puddled plots after final leveling, at the rate of 100 kgs. of seed per hectare. Barnyard grass [Echinochloa crus-galli (L.) Beauv] weed seeds were broadcast on the experimental plots at the rate of 10 kg per hectare in the Philippines, just before sowing the rice seeds. This was done to supplement the existing weed seed population in the trials and to increase the uniformity of weed density in each plot.

Following normal rice growing practice, the plots were irrigated and drained intermittently until just before herbicide application. For saturated conditions, irrigation water was drained from the experimental plots before application of herbicides. Irrigation water was re-introduced 4 to 5 hours thereafter. For flooded conditions water level was kept at 2 to 5 cm during application. Later, paddy water was maintained at a depth of 10 cm up until 10 days before harvest.

Herbicides were applied using a manually operated knapsack sprayer with a single fan type nozzle. Spray volumes of 300 litres/ha in the Philippines, 500 litres/ha in India, and 400 litres/ha in Malaysia were used. Weed control and phytotoxicity ratings were taken at 7, 14, 21 and 28 days after herbicide application and expressed as a percentage of the untreated plots. Weed control assessment were based on visual observations excepts in the Philippines where control was measured using the following formula:

$$\%\ \text{Weed control} = \frac{\text{number of infested quadrat in control plots} - \text{number of infested quadrat in treated plots}}{\text{number of infested quadrat in control plots}} \times 100$$

All data were analyzed using analysis of variance (ANOVA). Treatment means were compared using the DMRT and LSD as appropriate.

Results and Discussion

Efficacy on ECHCG (3-4 LS) under saturated condition

cyhalofop butyl 30% EC alone and tank mixed with PG 26-2 0.1% v/v was applied to three to four leaf stage E. crus-galli 14 days after rice seeding (DAS) at the rate of 30, 60, 120, 180 and 240 g a.i./ha Without PG 26-2, application rate of 240 g a.i./ha gave only 76%, and 78% control of barnyard grass, 28 days after application (DAA) in India and Philippines, respectively (Table 1). The same rate provided 95% and 99% control of barnyard grass in Malaysia. The variation in weed control can be attributed to the difference in grass weed population in each trial site.

The addition of adjuvant PG 26-2 (0.1% v/v) to cyhalofop butyl spray solution enhances its activity against E. crus-galli. Twenty eight days after application (28 DAA), cyhalofop butyl plus PG 26-2 (60 g a.i./ha + 0.1% v/v) provided 71% control of E. crus-galli in the Philippines and 91% and 92% control of the same weed in India and Malaysia, respectively. These levels of control are statistically equal to the weed control attained from cyhalofop butyl at 240 g a.i./ha without PG 26-2 in the Philippines and India. There was little dose response from 120-240 g a.i./ha of cyhalofop butyl plus 0.1% of v/v PG 26-2, in the Philippines, and from as low as 60 g a.i./ha in India and Malaysia. All these treatments provided barnyard grass control similar to standard treatments pretilachlor (300 g a.i./ha) and quinclorac (240 g a.i./ha).

The rate of cyhalofop butyl combined with PG 26-2 that provided more than 90% control of E. crus-galli was found to be between 120 and 180 g a.i./ha in the Philippines and between 60 to 120 g a.i./ha in India and Malaysia, respectively. This indicated the complimentary effects of PG 26-2 which enhanced herbicide uptake by the weeds (Sharma 1976). There was no phytotoxicity in any trials up to the highest rate tested.

Performance of cyhalofop butyl with and without PG 26-2 on E. crus-galli (3-4 LS) in flooded versus saturated condition

Cyhalofop butyl gave better control of E. crus-galli in saturated rather than flooded conditions. This effect was more pronounced when cyhalofop butyl (60, 120 and 180 g a.i./ha.) was applied without PG 26-2 at the 4 leaf to 2 tillering stage of E. crus-galli, (Table 2). Without PG 26-2, the rate of cyhalofop butyl required to provide > 90% control of E. crus-galli, at 28 DAA was 120 and 240 g a.i./ha under saturated and flooded conditions, respectively. To achieve > 90% control, 180 and > 240 g a.i./ha is needed under saturated and flooded condition, respectively. Results clearly indicated that the extent of surface area exposed to cyhalofop butyl spray had a major impact on its efficacy as a postemergence herbicide.

Again, the addition of PG 26-2 (0.1% v/v) improved the performance of cyhalofop butyl. All rates gave > 90% control of E. crus-galli at 28 DAA, either in saturated or flooded condition. No difference was noted between two water regimes. Results of this study indicated that by the addition of PG 26-2 cyhalofop butyl at 60, 120 and 240 g a.i./ha performs as well as pretilachlor (300 g a.i./ha) against E. crus-galli either in flooded or saturated conditions.

Performance of various rates of cyhalofop butyl and PG 26-2 combinations under different application timing

The activity enhancing effect of PG 26-2 when tank mixed with cyhalofop butyl was very marked (Table 3). While no statistical difference was noted in the enhancement effect between 0.1% v/v, 0.2% v/v and 0.4% v/v PG 26-2, treatments with 0.2 and 0.4% v/v PG 26-2 gave numerically higher weed control. Seven days after herbicide application (7 DAA), rates of cyhalofop butyl + PG 26-2 that provided > 90% control of E. crus-galli were 60 g a.i./ha + 0.4% v/v applied at 10 DAS and 100 g a.i./ha + 0.4% v/v applied at 10 DAS and 13 DAS. This result indicated that the effect of cyhalofop butyl on E. crus-galli is gradual. Fourteen days after application (14 DAA), the level of weed control dramatically increased in all cyhalofop butyl treatments. Treatments with 0.2 and 0.4% v/v PG 26-2 applied at 10-16 DAS gave > 90% control of E. crus-galli. Better efficacy obtained within this application timing can be attributed to the greater leaf surface area exposed to the cyhalofop butyl spray solution. This observation continued to be true up to the latest weed control rating period, at 28 DAA.

The trials showed that cyhalofop butyl + PG 26-2 at the rates evaluated had a wider application window than the standard herbicide, pretilachlor (300 g a.i./ha). When combined with PG 26-2 (0.2 and 0.4% v/v), it can be applied from 5 DAS to 16 DAS. No differences in weed control was noted between cyhalofop butyl + PG 26-2 treatments on application made at 10 DAS to 16 DAS. The fact that later application timing gave numerically better weed control of E. crus-galli means that commercial field application can be made up to 16 DAS. This feature of cyhalofop butyl offers the farmer greater flexibility in his herbicide application program for E. crus-galli and L. chinensis. This is applicable in direct seeded and transplanted rice, with complete selectivity to the rice crop.

Summary and Conclusion

Cyhalofop butyl alone and in combination with PG 26-2 was completely selective to direct seeded paddy rice. Generally, cyhalofop butyl performed better under saturated rather than flooded conditions. The addition of PG 26-2 (0.1% v/v enhanced its performance against E. crus-galli such that at rates of 60, 120 and 240 g a.i./ha performed as well as pretilachlor 300 g a.i./ha against E. crus-galli and L.

chinensis, either in flooded or saturated conditions. Increasing the rate of PG 26-2 to 0.2% v/v or 0.4% v/v further improved its performance. Rate as low as 60 g a.i./ha. applied at 5 DAS to 16 DAS provided consistent control of E. crus-galli. Herbicidal efficacy was statistically comparable to pretilachlor. To maximize the efficacy of cyhalofop butyl as a postemergent herbicide, application at 7 DAS to 16 DAS is recommended. This ensures sufficient leaf surface area of E. crus-galli and L. chinensis is exposed and available for the uptake of cyhalofop butyl.

Table 1. Efficacy of cyhalofop butyl 30% EC with and without PG 26-2 applied at 3-4 leaf stage (14 DAS) of ECHCG in direct seeded paddy rice

Treatment	Rate	Weed Control (%) 28 DAA		
	(g a.i./ha)	India	Malaysia	Philippines
cyhalofop butyl	30	25 cd	10 e	0 e
cyhalofop butyl	60	17 d	19 e	0 e
cyhalofop butyl	120	48 bc	34 de	27 d
cyhalofop butyl	180	43 c	71 c	45.5
cyhalofop butyl	240	76.5 ab	95 ab	78.5 b
cyhalofop butyl + PG 26-2	30+0.1% v/v	55 b	55 d	21.5 d
cyhalofop butyl + PG 26-2	60+0.1% v/v	91 a	92 b	71 b
cyhalofop butyl + PG 26-2	120+0.1% v/v	100 a	99 a	90 a
cyhalofop butyl + PG 26-2	180+0.1% v/v	100 a	100 a	90 a
cyhalofop butyl + PG 26-2	240+0.1% v/v	100 a	100 a	99 a
pretilachlor 300EC*	300	-	96 ab	93.5 a
quinclorac 50WP	240	-	94 ab	97 a
untreated check		0 e	0 f	0 e
LSD (.05)		30.91	6.5	17.6

* /Pre-emergence application 4 D A S

Table 2. Comparative performance of cyhalofop butyl 30% EC with and without PG 26-2 sprayed on saturated and flooded condition at 3-4 leaf stage of ECHCG (14 DAS) in direct seeded paddy rice, (Philippines February - May 1993)

Treatment	Rate	Weed control (%) 28 DAA		
	(g a.i./ha)	Saturated	Flooded	Difference
cyhalofop butyl	60	63	37	26 **
cyhalofop butyl	120	93	55	38 **
cyhalofop butyl	180	93	82	11 ns
cyhalofop butyl	240	94	98	-4 ns
cyhalofop butyl + PG 26-2	60+0.1% v/v	97	94	3 ns
cyhalofop butyl + PG 26-2	120+0.1% v/v	99	99	0 ns
cyhalofop butyl + PG 26-2	180+0.1% v/v	99	98	1 ns
cyhalofop butyl + PG 26-2	240+0.1% v/v	100	99	1 ns
Sofit 300EC*	300	91	85	6 ns
untreated check		0	0	0 ns

Percent control rating present the average of 4 replications.
Sofit applied at 4 DAS.
Water level is 0-1 cm and 6-10 cm for saturated and flooded condition, respectively.
Plant and weed height at spraying:
ORYSA = 20-25 cm
ECHCG = 25-30 cm

Table 3. Efficacy of various rates of cyhalofop butyl and PG 26-2 sprayed at different leaf stage of ECHCG in direct seeded paddy rice, (Philippines, Jan. to April and July to Nov. 1994. Figure entry mean of two seasons testing.

Treatments	Rate	Weed control (%) 28 DAA			
	(g a.i./ha)	5 DAS	10 DAS	13 DAS	16 DAS
cyhalofop butyl	60	39.5 e	11.5 ef	25.0 bcd	20 bc
cyhalofop butyl + PG 26-2	60+0.1%V/V	74.0 abc	65.0 cd	89.5 a	86 a
cyhalofop butyl + PG 26-2	60+0.2%V/V	84.0 abc	83.0 ab	93.0 a	94.0 a
cyhalofop butyl + PG 26-2	60+0.4%V/V	86.0 abc	95.0 a	98.0 a	97.0 a
cyhalofop butyl	80	53.0 cd	28 c	39.0 bc	23.0 bc
cyhalofop butyl + PG 26-2	80+0.1%V/V	90 a	70 bcd	94.0 a	96.0 a
cyhalofop butyl + PG 26-2	80+0.2%V/V	79 ab	88 ab	97.0 a	97.0 a
cyhalofop butyl + PG 26-2	80+0.4%V/V	82.0 ab	95.5 a	99.0 a	98.0 a
cyhalofop butyl	100	67.0 bc	58 d	43.0 b	41.0 b
cyhalofop butyl + PG 26-2	100+0.1%V/V	94.0 a	77 abcd	96.0 a	97.0 a
cyhalofop butyl + PG 26-2	100+0.2%V/V	82.0 ab	91.0 ab	98.5 a	99.0 a
cyhalofop butyl + PG 26-2	100+0.4%V/V	88.0 ab	96.0 a	91.0 a	99.0 a
pretilachlor 300 EC	300	95.0 a	5.0 ef	10 cd	4.0 cd
untreated check		0 f	0 f	0 d	0 d

Percent control ratings represent the average of 4 replications.
Sofit applied at 4 DAS.

LITERATURE CITED

Bernasor, P.C. and S.K. De Datta. 1983. Integration of Cultural Management and chemical control of weeds in broadcast-seeded flooded rice. Proc. 9th Conference Asian Pacific Weed Sci. Soc. 1983, Manila Philippines p 135-137.

P.G. Ray, R.G. Pews, J. Flake, J. Secor and A. Hamburg. 1993. Cyhalofop Butyl A new graminicide for use in rice. Proc. 14th Conference Asian Pacific Weed Sci. Soc. 1993, Brisbane, Australia pp 41-45.

Sharma, V.S. 1976. Surfactants and herbicide efficiency. Planters Chronicle, 71 (8).

Smith, R.J., Jr. and W.C. Shaw. 1966. Weeds and their control in rice production. Agric. Handb. 292. USDA, Washington, D.C. 64 p.

CYHALOFOP BUTYL : A GRASS HERBICIDE UNDER DEVELOPMENT FOR RICE IN KOREA

Y. K. MIN.
DowElanco Int'l. Korea Branch
142-35, Samsung-dong, Kangnam-ku, Seoul, 135-090, Korea

Abstract : Cyhalofop-butyl (trade name : Clincher) is a new grass killer being developed in Korea for transplanted rice as well as direct seeded rice cultivation. In field trials, Cyhalofop-butyl showed excellent selectivity to rice cultivars and provided excellent control efficacy on grasses including Echinochloa species, Digitaria species and other annual grasses post-emergence application, 3-5 leaf stage(Ls) of grasses, at the rates of 180-300g ai/ha.
No rice injury by Cyhalofop-butyl combinations were observed in direct seeded rice and infant seedling (8 - 10 days old seedling) rice.

Key words : Cyhalofop-butyl, water seeded, dry seeded, Echinochloa species, Digitaria species.

Introduction

Cyhalofop-butyl, coded XDE-537 or DEH-112, (R)-butyl 2-(4-(4-cyano-2-fluorophenoxy) phenoxy) propionate is a new post-emergence aryloxy-phenoxy propionate herbicide discovered by DowElanco which controls a broad spectrum of grass weeds, including species of Echinochloa, Digitaria, Eleusine, Leptochloa and Setaria (1, 3).
Cyhalofop-butyl has high selectivity between rice and target grass weeds, the safety margin for Japonica rice was over 10 times greater than the rate required for control of E. crus-galli (2).
Cyhalofop-butyl is readily absorbed through leaf and sheath of grasses, and it is phloem mobile and then accumulates in the meristematic region of plant.
Cyhalofop-butyl kills target grass weeds within one week after appliaction.
Cyhalofop-butyl is now under development for weed control on transplanted rice as well as direct seeded rice in Asia pacific, America and Europe.
The present paper describes the biological performance of Cyhalofop-butyl through field trials conducted in Korea and suggestes the recommendations of Cyhalofop-butyl application for different rice cultivation, transplanting or direct seeding practices in Korea.

Materials and Methods

Cyhalofop-butyl has been extensively tested under different cultivation of rice fields for past 2 years in total of 16 field trials through the Korea.

Dry seeded rice

Dry seed of rice was drill seeded on dry soil and disked to cover by tractor attachable rice drill seeder.

The sprayable formulation of cyhalofop-butyl single and combinations with bentazon and pendimethalin were sprayed over the top of weeds and rice by a knapsack sprayer at 1000L/ha of spray volume when Echinochloa crus-galli (ECHCG) grew up 3, 4 and 5 Ls at 15, 20 and 25 days after seeding (DAS).

For the 20-40 days after treatment, the test field maintained upland condition.

Water seeded rice

Pregerminated seed of rice was broadcast sown in water by hand after puddling.

The granular formulation of cyhalofop-butyl combinations with sulfonyl ureas were applied into water at 15-20 DAS when ECHCG grew up to 3 leaf stage.

The water depth in the test plots was maintained at 3-4cm deep during the trial period.

Transplanted rice

Rice seedling at 2 Ls were transplanted into the paddy field. The granular formulation of cyhalofop-butyl combinations with sulfonyl ureas were applied into water when ECHCG grew up to 3 Ls at 15-20 days after transplanting (DAT).

The water management was maintained flooded condition during the trial period.

Rescue treatment (Post-emergence)

In-transplanted rice paddy, the sprayable formulation of cyhalofop-butyl single and combinations were sprayed over the top of plants by a kanpsack sprayer at 1000L per ha of spray volume when weeds grew up 20-30cm of plant height at 32-35DAT.

Trials with a plot sized 3x5m were block randomised with 3 replications.

Plots were visually assessed at various times during the growing season.

Results and Discussion

Since newly developed direct seeding methods in dry and flooded paddy were introduced in 1992 and are being rapidly extended to farmer, cyhalofop-butyl was tested to determine its feasibility as a rice herbicide for new cultivation practices during 1993-1994.

This presentation summarizes several trial results obtained from different cultivation conditons.

Dry seeded rice (table 1)

Cyhalofop-butyl EC at 300g ai/ha provided excellent control upto 5Ls of ECHCG and Digitaria sanguinalis except for sedge and broad leaves without phytotoxicity to dry seeded rice.

Annual weeds including ECHCG predominant in dry paddy were well controlled by cyhalofop-butyl combinations with pendimethalin at use rate of 240 + 1250g ai/ha and bentazon sodium salt at rate of 240+1440g ai/ha, when the combinations were treated at 20DAS. Negligible phytotoxicity was observed on 2-3 leaf of rice.

Table 1. Effect of Cyhalofop-butyl application at post-emergence in dry seeded rice, 1993-1994 / Korea (average of 3 trials)

Treatment	Appli. date	Dose g ai/ha	Weed control (%) at 14 DAA**				Crop injury (0-9)****
			ECHCG*	DIGAD	CYPMI	B/L	
Cyhalofop	15DAS***	180g	85.6	74.7	12.5	21.8	0.0
- butyl	(3Ls)*****	240g	93.3	81.4	25.8	14.0	0.0
30%EC		300g	98.2	100	10.9	29.5	0.0
	25DAS	180g	82.1	66.8	15.4	15.3	0.0
	(5Ls)	240g	87.4	73.2	21.8	20.2	0.0
		300g	93.8	91.5	16.4	13.8	0.0
Cyhalofop	20DAS	240+1250	93.0	92.0	75.0	95.0	1.0
+ Pendimethalin	(4Ls)						
(4.8+25%)Ec							
Cyhalofop	20DAS	240+1440	90.0	93.0	100	89.0	1.0
+ Bentazon (Na)	(4Ls)	300+1800	93.0	90.0	100	100.0	1.0
(3+20%)ME							

* ECHCG : Echinochloa crus-galli, DIGAD : Digitaris sanguinalis
CYPMI : Cyperus microiria B/L : annual broad leaves
** DAA : days after application
**** Crop injury rating (0: no injury, 9: complete death of rice)
*** DAS : days after seeding ***** Ls : leaf stage of ECHCG

Water seeded and infant seedling transplanted rice (table 2, 3)

At 180g ai/ha of 2-way and 3-way combinations of cyhalofop-butyl and sulfonyl ureas with or without pretilachlor gave excellent control upto 3 Ls of ECHCG and other annual and perennial broad leaves and sedges when applied 15-20 DAT or DAS. Slight phytotoxicity were observed on water direct seeding and infant seedling rice.

Rescue treatment (table 4)

For control of late emerged ECHCG, Eleocharis kuroguwai and Sagittaria trifolia, which are most troublesome weeds at rice tillering stage, cyhalofop-butyl at the rate of 240g ai/ha mixed with bentazon or cinosulfuron + propanil showed good control of 4 - 5Ls of ECHCG and perennial weeds simultaneously.

Table 2. Average weed control of Cyhalofop products at early post-emergence in water seeded rice, 1993-1994 / Korea (average of 6 trials)

No.	Treatment (Products)	Appli. date	Dose ai/ha	Weed control (%) at 30 DAA						Crop injury
				ECHCG	MOOVA	SCPJU	CYPSE	ELOKU	SAGTR*	(0-9)
1)	Cyhalofop + Bensulfuron Gr.	15-20DAS (up to 3Ls)	180g + 51g	85.6	100	99.3	74.5	81.0	90.0	1.0
2)	Cyhalofop + Bensulfuron + Pretilachlor Gr.	"	180 + 51 + 300	90.0	100	100	96.7	89.1	100	1.0
3)	Cyhalofop + Pyrazosulfuron Gr.	"	180 + 21	87.4	100	99.0	100	94.7	84.4	1.0
4)	Cyhalofop + Pyrazosulfuron + Pretilachlor Gr.	"	180 + 21 + 300	90.3	100	98.3	100	84.3	84.5	1.0
5)	Cyhalofop + Imazosulfuron Gr.	"	180 + 75	90.4	100	100	100	88.0	100	1.0
6)	Cyhalofop + Imazosulfuron + Pretilachlor Gr.	"	180 + 75 + 300	90.7	99.8	93.2	93.8	85.3	100	1.0

Table 3. Average weed control of Cyhalofop products at early post-emergence in transplanted rice, 1993-1994 / Korea (average of 5 trials)

No.	Treatment (Products)	Appli. date	Dose ai/ha	Weed control (%) at 30 DAA						Crop injury
				ECHCG	MOOVA	SCPJU	CYPSE	ELOKU	SAGTR*	(0-9)
1)	Cyhalofop + Bensulfuron + Pretilachlor Gr.	15-20DAT (3Ls)	180g + 51g + 300	90.8	99.1	100	98.7	88.5	100	1.0
2)	Cyhalofop + Pyrazosulfuron + Pretilachlor Gr.	15-20DAT (3Ls)	180 + 21 + 300	97.3	98.5	100	95.8	97.7	99.8	1.0
3)	Cyhalofop + Imazosulfuron + Pretilachlor Gr.	15-20DAT (3Ls)	180 + 75 + 300	94.2	99.1	97.5	97.1	94.6	95.0	1.0

* SCPJU : *Scirpus juncoides* CYPSE : *Cyperus serotinus*
ELOKU : *Eleocharis kuroguwai* SAGTR : *Sagittaria trifolia*

But cyhalofop-butyl + cinosulfuron 2-way combo provided poor control of ECHCG due probably to the antagonisum between cyhalofop and cinosulfuron.

Table 4. Effect of Cyhalofop-butyl combinations application as rescue treatment at post-emergence in transplanted rice. 1994 (average of 2 trials)

No.	Treatment (Products)	Appli date	Dose ai/ha	Weed control(%) at 21DAA ECHCG	LUDPR	SCPJU	ELOKU	SAGTR*	Crop injury
1)	Cyhalofop	35DAT	240g	99.5	100	100	97.1	100	(0-9)
	+ Bentazon ME	(3tillers)	+ 1440g						1.0
2)	"	35DAT	300	98.3	100	95.5	97.1	100	
			+ 1800						1.0
3)	Cyhalofop	32DAT	240	82.3	47.9	92.7	85.6	89.2	
	+ Cinosulfuron	(4tillers	+ 20						1.0
	+ Propanil WDG	of rice)	+ 250						
4)	Cyhalofop	32DAT	+ 240	58.4	60.1	85.3	90.7	83.5	
	+ Cinosulfuron WP		+ 20						1.0
5)	Cyhalofop EC	32DAT	300	90.3	0	0	0	0	0

* LUDPR : Ludwigia prostrata SAGTR : Sagittaria trifolia

From the results the following conclusion can be made.

1) Cyhalofop-butyl products at 180-300g ai/Ha gave wide application window of 5-20DAS(DAT) and excellent control of 3-5 Ls of ECHCG and annual grasses and there were no phytotoxicity either on water seeded or dry seeded, transplanted rice (8-10 days old seedling).

2) The effective application method were estblished as follows;

- Dry seeded rice

For the first 30-40 days until rice leaf stage reaches 4-5 leaves, the field is maintained in dry condition and changed to flooded condition as a normal paddy rice field.

Therefore. the sequential application is essential for dry seeded rice, first one being during the period of dry condition and another during the period of flooded condition.

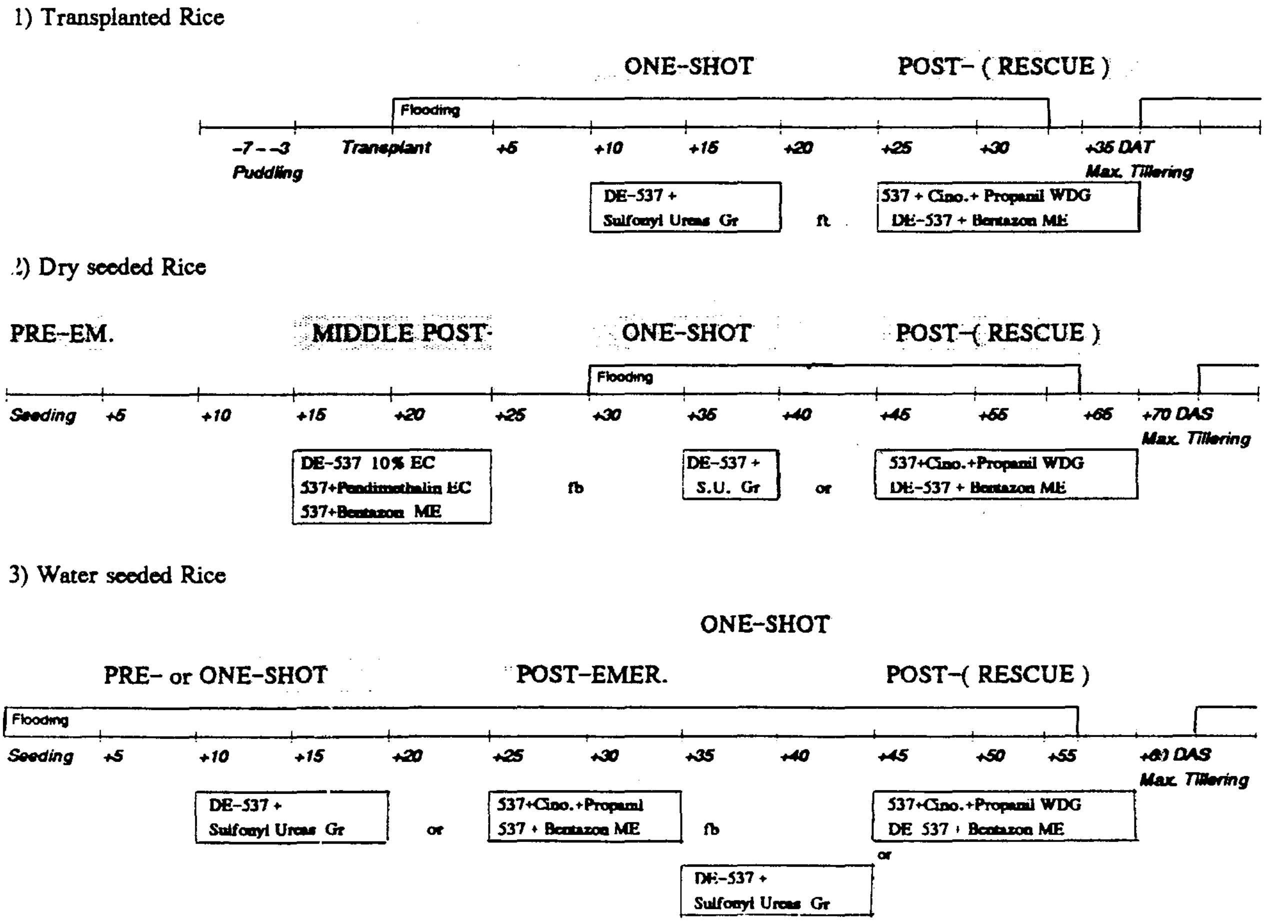
Good herbicidal performance can be achieved by foliar application of Cyhalofop-butyl at 20-25 DAS (3-4Ls of ECHCG) and irrigation done at 7-10 days after application (30-35 DAS). One additonal cyhalofop-butyl combinations Gr application is needed 5-15days after permanent irrigaton about 35-45 DAS.

- Water seeded rice

Rice is seeded under flooded condition or in the puddling soil and the flooded condition maintained as normal paddy condition, cyhalofop-butyl + sulfonyl urea combinations are applied at 10-20 DAS (2-3 Ls of ECHCG) for control of annual and perennial weeds. If needed, cyhalofop-butyl sprayables can also be applied at 45-60 DAS for control of late emerged weeds or escaped weeds including ECHCG.

- **Transplanted rice**
  Cyhalofop-butyl + Sulfonyl urea combinations are applied at 10-20 DAT (2-3Ls of ECHCG) for control of annual and perennial weeds, and cyhalofop-butyl + bentazon or cinosulfuron combinations can also be applied if the late emerged weeds are still infested up to the tillering stage of rice.

Recommendations of Cyhalofop- butyl (DE-537) Application



References

1. P.G. Ray, P.G. Pews. J. Flake, J. Secor and A. Hamburg, 1993, Proc. 14th Asian-Pacific Weed Conference, brisbane, pp41-45.
2. Matsumoto T, K. Matsuya, H. Katahashi. N. Kondo, Y. Imai. 1993, Proc. 14th Asian-Pacific Weed Conference, brisbane, pp149-153.
3. Y. Imai, M. Chen, T. Matsumoto, P.G. Ray, G. Pews. J. Flake, J. Secor and A. Hamburg, 1994, Weed Research Japan Vol 39(Proc.) pp16-17.

CYHALOFOP BUTYL : A SELECTIVE GRAMINICIDE
- COMBINATION STUDY WITH BENTAZONE IN RICE JAPAN -

K. Matsuya, N. Kondo, Y. Imai, T. Matsumoto
DowElanco Division, Dow Chemical Japan Limited,
Tennoz Central Tower, 2-24, Higashi Shinagawa 2-chome, Shinagawa-ku
Tokyo 140, Japan

Abstract. Cyhalofop butyl, (R)-butyl 2-(4-(4-cyano-2-fluorophenoxy)phenoxy) propionate is a new grass herbicide having outstanding selectivity in rice with a broad application window (1-6.5 leaf) on barnyardgrass (*Echinochloa crus-galli*). It demonstrates consistent performance under various paddy conditions. When cyhalofop butyl was tank-mixed with bentazone Na and sprayed, it controlled all key weeds of *E. crus-galli, Monochoria vaginalis, Cyperus difformis, Scirpus juncoides, Cyperus serotinus, Sagittaria pygmaea, Eleocharis kurogwai* under drained conditions of paddy with the application timing up to 5 leaf stage of *E. crus-galli* without any crop damage on rice. Ready mixed formulation (micro emulsion, ME) of cyhalofop butyl and bentazone Na showed equivalent efficacy and crop safety to tank-mixture.

Key words. Cyhalofop butyl, bentazone Na, combination, spray application

INTRODUCTION

Cyhalofop butyl, coded (X)DE-537 (DEH-112 in Japan) is a new post-emergence aryloxyphenoxy propionate graminicide discovered and being developed by DowElanco which controls a broad spectrum of grass weeds, including species of *Echinochloa, Brachiaria, Cynodon, Digitaria, Eleusine, Leptochloa, Panicum, Setaria and Sorghum* (1). Cyhalofop butyl possesses high selectivity between rice and target grass weeds, and it controlled *E. crus-galli* up to 4 leaf stage as a granule application and up to 6.5 leaf stage as a foliar spray without injury to rice (2). Foliar spray is one of the effective application methods which provides rapid knockdown efficacy on high leaf stage of *E. crus-galli* with short soil residuality. This paper describes combination study results of cyhalofop butyl and bentazone Na for the control of key weeds with spray application in rice.

MATERIALS AND METHODS

Field trials. From 1992 to 1994 season, field trials were carried out at Fukuoka Field Station of DowElanco division in Japan. After paddy field was rotary-tilled, puddled and levelled, target weeds were planted. Rice seedlings (variety: Koshihikari) at 2.5 leaf stage were transplanted into the paddy field approximately 2 to 3 cm in soil-depth by transplanter a few days after levelling. The plots were separated by corrugated plastic boards. Trials with a plot size of 2×3 m were block randomised with 3 replications. Formulations were sprayed over the top of plants by a knapsack sprayer (1000 ℓ/ha) at appropriate timings under drained conditions. The plots were flooded to 3 to 4 cm water in depth at 3 days after application and the water level was kept during trial period.
Weed control efficacy and crop injury were visually evaluated comparing with untreated plots at 1, 2, 3 and 4 weeks after application. The soil characteristics were alluvial soil with 55.9% sand, 26.7% silt, 17.5% clay, 3.4% organic matter, CEC 20.8 meq/100 g and pH 6.5. Water loss was observed as 0.5 cm in depth in a day.

Pot trials. Soil was puddled and levelled in the 1/5,000 are Wagner's pot and target weeds planted onto the soil surface. After growing up to appropriate leaf stage in greenhouse, formulations were applied and the plots were managed in similar way to field trials. Temperature in greenhouse was kept at 30°C in the daytime and 20°C in the night.

All trials were conducted with 3 replications. Formulations used were [A]: 30% cyhalofop butyl · EW, [B]: 3% cyhalofop butyl · ME. [C]: 3/20% cyhalofop butyl/bentazone Na · ME. [D]: 5/35% cyhalofop/ bentazone (H) · WP. [E]: 40% bentazone Na · SL.

RESULTS AND DISCUSSION

Efficacy of tank mixture on *E. crus-galli* (field trial). Cyhalofop butyl 30% EW at 180 to 300 g ai/ha showed more than 95% control of *E. crus-galli* at 5 leaf stage and its tank-mixtures with bentazone Na 40% SL at 2000 g ai/ha gave similar high efficacy. There was no difference between cyhalofop butyl alone and mixture with bentazone Na in efficacy including the days required for completion of herbicidal action (Fig. 1).

Efficacies on key weeds and crop safety of tank-mixture (field trial). Cyhalofop butyl 3% ME at 300 g ai/ha showed high efficacy on 5 leaf stage of *E. crus-galli*, while it did not control any other key weeds. Bentazone Na 40% SL at 2000 g ai/ha controlled all key weeds except *E. crus-galli*. Tank-mixture of these two formulations showed high efficacy on all key weeds as well as each formulation. No phytotoxicity was observed at any treatments during the trial period (Fig. 2).

Efficacies on key weeds and crop safety of mixed formulation - ME (field trial). Mixed ME formulation controlled all key weeds as well as cyhalofop butyl on *E. crus-galli* or bentazone Na alone on other key weeds at 5 leaf stage of *E. crus-galli* without any phytotoxicity (Fig. 3).

Dose response of mixed formulation - ME (field trial). Mixed ME formulation at the lowest rate of 180/1200 g ai/ha as cyhalofop butyl/bentazone gave similar efficacy on key weeds to 300/2000 g ai/ha. There was no crop damage to rice even at the highest rate of 360/2400 g ai/ha (Fig. 4).

Efficacies on annual weeds of mixed formulation - WP (pot trial). Mixed WP formulation at 240/1680 and 300/2100 g ai/ha as cyhalofop butyl/bentazone (H) showed equivalent efficacies on annual weeds to ME formulation at 240/1600 and 300/2000 g ai/ha, respectively, at 5 leaf stage of *E. crus-galli* (Fig. 5).

Efficacy of mixed ME formulation at different leaf stage (field trial). ED90 value indicated that cyhalofop butyl required about 300 g ai/ha at 5 leaf stage of *E. crus-galli*, while more than 400 g ai/ha was needed for 6 and 7 leaf stage with mixed ME formulation (Table 1).

REFERENCES

1. Ray, P.G., Pews, R.G., Flake, J., Secor, J. and Hamburg, A. 1993. Cyhalofop butyl : Grass herbicide - Field performance in rice in Japan - Proceeding of 15th APWSS Conference, Brisbane, Australia, pp41-45.
2. Matsumoto, T., Matsuya, K., Katahashi, H., Kondo, N., Imai, Y. 1993. Cyhalofop butyl : Grass herbicide - Field performance in rice in Japan - Proceeding of 15th APWSS Conference, Brisbane, Australia, pp 149-152.

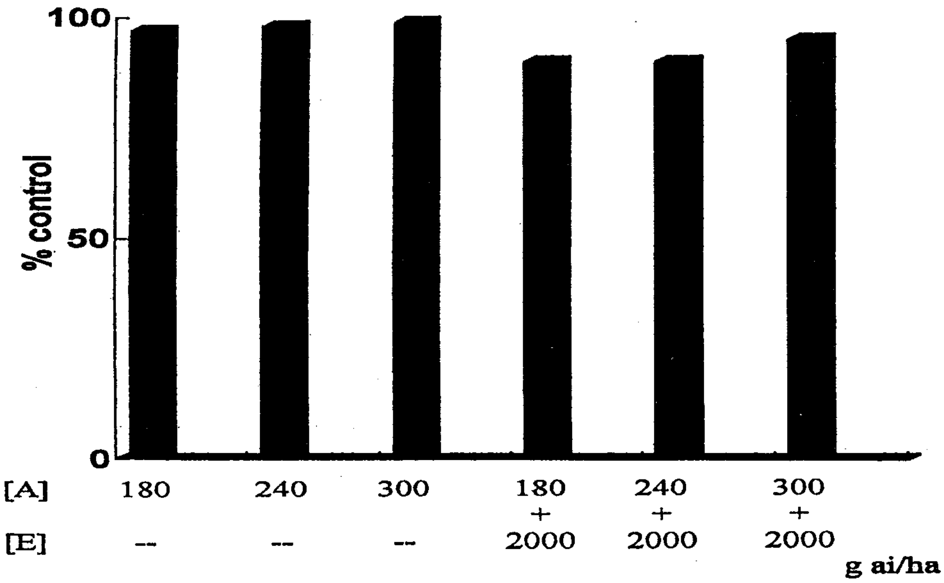


Fig. 1. Efficacy of tank-mixture of cyhalofop butyl and bentazone

Test plant	:	Echinochloa crus-galli
Timing	:	5 leaf stage
Formulation	:	[A] 30% cyhalofop butyl, EW
		[E] 40% bentazone Na, SL
Spray volume	:	1000ℓ/ha
Water depth	:	drained condition at application
Observation	:	3 weeks after application

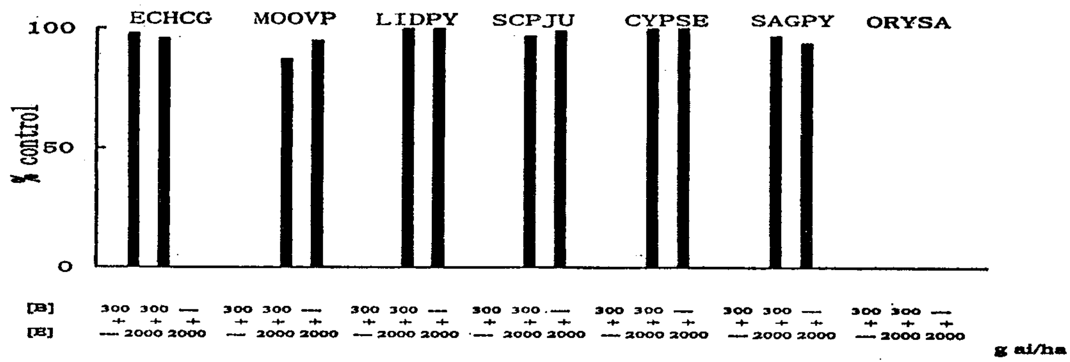


Fig. 2. Efficacies on key weeds and crop safety of tank-mixture of cyhalofop butyl and bentazone

Test plant		
ECHCG	:	Echinochloa crus-galli
MOOVP	:	Monochoria vaginalis
LIDPY	:	Lindernia pyxidaria
SCPJU	:	Scirpus juncoides
CYPSE	:	Cyperus serotinus
SAGPY	:	Sagittaria pygmaea
ORYSA	:	Oryza sativa
Timing	:	5 leaf stage
Formulation	:	[B] 30% cyhalofop butyl, EW
		[E] 40% bentazone Na, SL
Spray volume	:	1000ℓ/ha
Water depth	:	drained condition at application
Observation	:	3 weeks after application

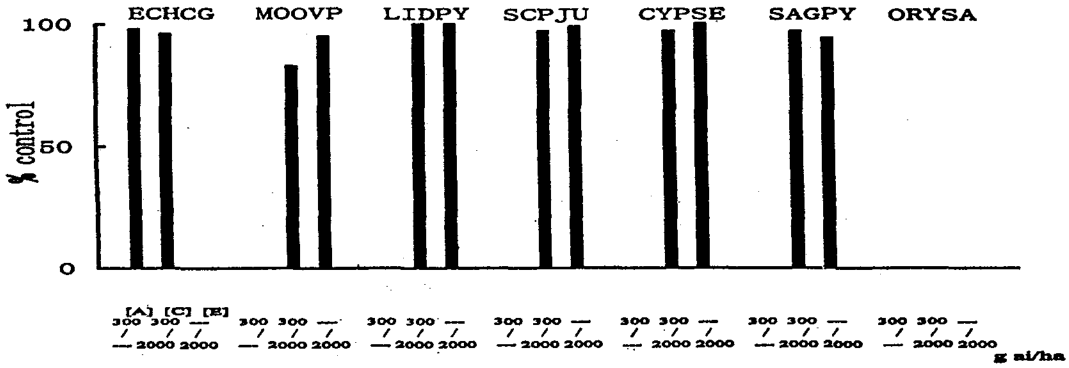


Fig. 3. Efficacies on key weeds and crop safety of mixed formulation of cyhalofop butyl and bentazone

Test plant		
ECHCG	:	Echinochloa crus-galli
MOOVP	:	Monochoria vaginalis
LIDPY	:	Lindernia pyxidaria
SCPJU	:	Scirpus juncoides
CYPSE	:	Cyperus serotinus
SAGPY	:	Sagittaria pygmaea
ORYSA	:	Oryza sativa
Timing	:	5 leaf stage
Formulation	:	[C] 3/20% cyhalofop butyl/bentazone, ME
		[A] 30 % cyhalofop butyl, EW
		[E] 40 % bentazone Na, SL
Spray volume	:	1000ℓ/ha
Water depth	:	drained condition at application
Observation	:	3 weeks after application

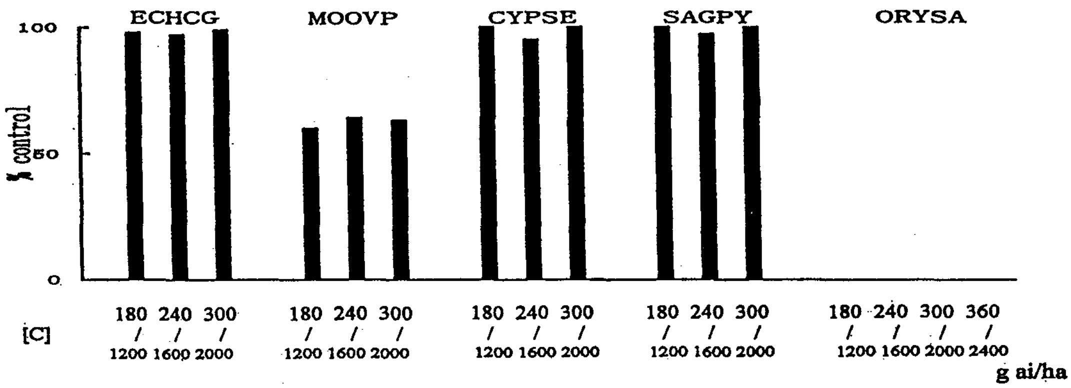


Fig. 4. Dose response of mixed formulation (ME) of cyhalofop butyl and bentazone to key weeds

Test plant		
ECHCG	:	Echinochloa crus-galli
MOOVP	:	Monochoria vaginalis
CYPSE	:	Cyperus serotinus
SAGPY	:	Sagittaria pygmaea
ORYSA	:	Oryza sativa
Timing	:	5 leaf stage of ECHCG
Formulation	:	[C] 3/20% cyhalofop butyl/bentazone Na, ME
Spray volume	:	1000ℓ/ha
Water depth	:	drained condition at application
Observation	:	3 weeks after application

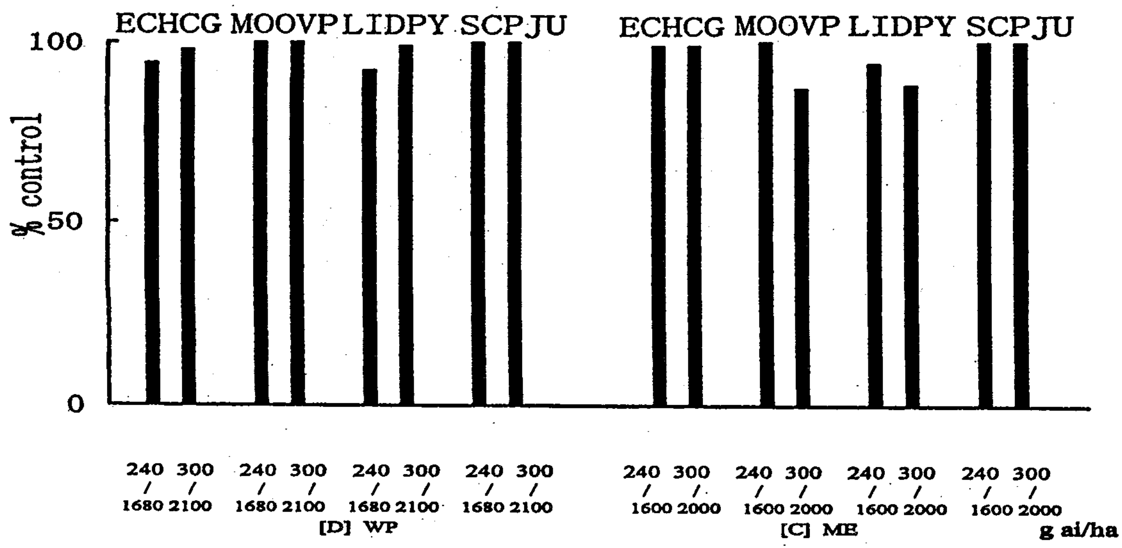


Fig. 5. **Efficacy of mixed formulation (WP) of cyhalofop butyl and bentazone (H)**

Test plant	:	**Echinochloa crus-galli**
Timing	:	**5 leaf stage**
Formulation	:	**[D] WP 5/35% cyhalofop butyl/bentazone (H)**
		[C] ME 3/20% " /bentazone Na,
Spray volume	:	**1000ℓ/ha**
Water depth	:	**drained condition at application**
Observation	:	**3 weeks after application**

Table 1 Efficacy of mixed formulation (ME) of cyhalofop butyl and bentazone on different leaf stage of Echinochloa crus-galli

Timing	:	2, 3, 4, 5, 6, 7 leaf stage
Formulation	:	[C] 3/20% cyhalofop butyl/bentazone Na, ME
Spray volume	:	1000ℓ/ha
Water depth	:	drained condition at application
Observation	:	3 weeks after application

Leaf stage	2	3	4	5	6	7
ED 90 g ai/ha	143	244	326	323	>420	>600

CYHALOFOP BUTYL MIXED WITH POLYGLYCOL 26-2 FOR POSTEMERGENT BARNYARDGRASS CONTROL IN RICE

M. CHEN[1], Y. IMAI[1], N. KONDO[2], K. MATSUYA[2], P. G. RAY[3]

[1]DowElanco Pacific Ltd., Wanchai, Hong Kong
[2]DowElanco Div., Dow Chemical Japan Ltd., Higashi-Shinagawa, Tokyo, Japan
[3]DowElanco Discovery Research, Zionsville Road, Indianapolis, USA

Abstract. Cyhalofop butyl is a novel grass herbicide with complete selectivity and wide application window for grass control in rice. In an effort to establish more economical and reliable weed control with cyhalofop butyl, it was found that the addition of an adjuvant polyglycol 26-2 (PG 26-2) - an alkyl phenolic glycol ether, enhanced its efficacy. No reduction in crop safety was observed under a variety of conditions. When PG 26-2 was added to the spray solution at 0.1-0.4% v/v, 80-120 g a.i./ha of cyhalofop butyl was required to control 3-4 leaf barnyardgrass. Without PG 26-2, 180-240 g ai/ha was required to get the same level of control. A special EC formulation of cyhalofop butyl containing PG 26-2 gave the same level of activity as tank mixture. Cyhalofop butyl at 960 g ai/ha with PG 26-2 was completely selective. The addition of PG 26-2 also significantly improved rainfastness of cyhalofop butyl.

Key words. cyhalofop butyl, adjuvant, Polyglycol 26-2, efficacy, barnyardgrass

Introduction

Cyhalofop butyl (XDE-537, DEH-112), (R) butyl-2-(4-(4-cyano-2-fluorophenoxy) phenoxy) propionate is a new selective rice herbicide, discovered by DowElanco. Development of this compound for field use is on-going in global scale for both direct seeded rice and transplanted rice. This compound has shown flexibility which allows various ways of application - single or combination use; granule, foliar spray or direct water application of a liquid formulation, etc. To establish more economical and reliable weed control with cyhalofop butyl when applied as a foliar spray, several trials were conducted in an experimental farm in Pingtung, Taiwan. This paper describes optimization of foliar spray technology of cyhalofop butyl by using an adjuvant - Polyglycol 26-2 (PG 26-2): an alkyl phenolic glycol ether.

Materials and Methods

The following cyhalofop butyl formulations were used in the trials: cyhalofop butyl 30% EC and cyhalofop butyl 10% EC containing PG 26-2 at 50% (GFH-342). Trade name and chemical name of all the adjuvants tested were listed below:
Polyglycol 26-2: alkyl phenolic glycol ether
Surfinol TGE: acetylene glycol surfactant
Silwett L-77: silicone surfactant
Ortho X-77: polyoxyethylene alkylaryl ether
Sunspray oil: 97% paraffin oil and 3% nonionic emulsifier
Atplus 411F: 83-85% paraffin oil and 15-17% nonionic emulsifier
Kumiten: polyoxyethylene nonylphenyl ether

Field trials were conducted from December 1992 to December 1994 in the experimental farm in Pingtung, Taiwan. The trials were conducted by using a randomized complete block design with three replications. Plot size was 0.4 by 0.4 meter, 2 by 2 meter or 2 by 5 meter for efficacy or phytotoxicity trials. Oxford Precision Sprayer fitted with 4 flatfan nozzles (Lurmark 03-F80) was used in a 2 by 2 meter or 2 by 5 meter plot and self-refilling syringe fitted with Teejet TN-3 nozzle was used in a 0.4 by 0.4 meter plot. Chemicals were sprayed over the top of the plants at appropriate leaf stage with a spray volume of 600 l/ha unless otherwise mentioned. Track sprayer fitted with 8005E nozzle was used to spray chemical and simulated rainfall in a plastic pot 15 cm in diameter for rainfastness study in greenhouse. Oxford Precision Sprayer fitted with 4 flatfan nozzles (Lurmark 03-F80) was used to spray chemical in a 1 by 2 meter plot in dry direct seed rice and simulated rainfall was applied by high pressure sprayer in rainfastness trial under field condition.

All the test plots were flooded with 3-5 cm water level throughout the test period in paddy trials. Water management in dry direct seeded rice was according to traditional agricultural practice. Barnyardgrass (Echinochloa crus-galli, ECHCG) was pre-germinated and inoculated into the test plots artificially. Soil in the field was Loam composed of 28.6% sand, 45.1% silt and 26.3% clay with 2% organic matter and pH 7.1. Visual assessment of weed control was made at 2, 3 and/or 4 weeks after application (WAA). Ratings reflect mean percentage biomass reduction relative to untreated where 0% = no effect or no injury and 100% = complete control or complete kill.

Results and Discussion

Selection of the adjuvants. Seven adjuvants (i.e., PG 26-2, Ortho X-77, Silwett L-77, Surfinol TGE, Kumiten, Sunspray oil and Atplus 411F) were tested their effect on the efficacy of cyhalofop butyl. Chemicals were applied at 2-3 leaf stage of barnyardgrass in a monoculture. Among all the adjuvants tested, PG 26-2 and Surfinol TGE provided the best enhancement on the efficacy of cyhalofop butyl. At 0.1% concentration, both PG 26-2 and Surfinol TGE provided about 2.7 fold enhancement of cyhalofop butyl barnyardgrass activity than it was applied alone (Table 1). When considered biological effect and economical aspects, PG 26-2 was the best adjuvant selected for further development.

Table 1. Efficacy of cyhalofop butyl 30% EC alone or with the addition of adjuvant against 2-3 leaf of barnyardgrass

Adjuvant	Concentration (%)	% Control at 2 WAA 60	120 (g a.i./ha)	240	GR 80 (g a.i./ha)
None		28	57	87	197
Polyglycol 26-2	0.1	75	89	98	74
Surfinol TGE	0.1	73	92	98	74
Ortho X-77	0.1	65	93	99	81
Silwett L-77	0.1	58	93	98	89
Sunspray oil	0.1	38	77	98	123
Atplus 411F	0.1	37	72	97	134
Kumiten	0.1	57	68	91	154

Percent control ratings represent the average of 3 replications.
Spray volume was 600 l/ha and plot size was 0.4 m by 0.4 m.

Optimization. Cyhalofop butyl 30% EC with different concentrations of PG 26-2 in the spray solution was tested their efficacy and phytotoxicity on 2-3 and 4-5 leaf stage of barnyardgrass in transplanted Japonica rice. Results showed that the higher the concentrations of PG 26-2 in the spray solution the better the efficacy and the faster the herbicidal symptom developed (Table 2). Over 90% control of barnyardgrass at 4 WAA was obtained by cyhalofop butyl at 60 g a.i./ha with PG 26-2 at 0.1-0.4% and at 120 g a.i./ha with PG 26-2 at 0.2-0.4% when treated with barnyardgrass at 2-3 and 4-5 leaf stage respectively. No phytotoxicity on rice was observed in plot treated with cyhalofop butyl at 360 g ai/ha with the addition of 0.4% PG 26-2 (the highest rate tested) up to 4 WAA.

Pre-mix formulation. A prototype of PG 26-2 incorporated cyhalofop butyl EC formulation (GFH-342 10% EC containing PG 26-2 at 50%) was tested its efficacy and phytotoxicity in comparison with cyhalofop butyl 30% EC alone or tank mixed with PG 26-2 at 0.1% under 250, 500 and 1000 l/ha spray volume conditions against 3-4 leaf stage of barnyardgrass in transplanted Japonica rice. Results indicated that the amount of active ingredient and the concentration of PG 26-2 in the spray solution were obviously the key factors to determine the efficacy of both pre-mix formulation and tank mixtures of cyhalofop butyl (Table 3). At a spray volume 250 l/ha, the efficacy of all the formulations tested was slightly better than that of spray volume 500 l/ha. Both 250 and 500 l/ha sprays provided significantly higher activity than that of 1000 l/ha spray. Run-off effect could be the major factor to reduce cyhalofop butyl activity under the 1000 l/ha spray. A prototype PG 26-2 incorporated cyhalofop butyl EC formulation proved that it was achievable to make cyhalofop butyl with PG 26-2 as an pre-mix formulation with good efficacy under the spray volume not higher than 500 l/ha.

Table 2. Efficacy and phytotoxicity of cyhalofop butyl 30% EC with the addition of different concentrations of PG 26-2 at 4 WAA

		(% Control)				(% Injury)			
	Concentration	Cyhalofop butyl (g a.i./ha)				Cyhalofop butyl (g a.i./ha)			
Adjuvant	(v/v)	60	120	240	360	60	120	240	360
		ECHCG 2-3 LF				ORYSA 4 LF			
PG 26-2	0.4%	99	100	100	100	0	0	0	0
	0.2%	97	100	100	100	0	0	0	0
	0.1%	90	99	100	100	0	0	0	0
	0.05%	88	98	100	100	0	0	0	0
	0.025%	83	97	100	100	0	0	0	0
		ECHCG 4-5 LF				ORYSA 6 LF			
PG 26-2	0.4%	83	97	100	100	0	0	0	0
	0.2%	67	93	98	100	0	0	0	0
	0.1%	70	85	97	100	0	0	0	0
	0.05%	52	83	99	100	0	0	0	0
	0.025%	38	72	92	100	0	0	0	0

Percent control ratings represent the average of 3 replications
ECHCG: Echinochloa crus-galli, barnyard grass
ORYSA: Oryza sativa, japonica variety TN-67
Spray volume was 600 l/ha and plot size was 2 m by 2 m.

Table 3. Efficacy of cyhalofop butyl EC formulation alone or incorporated with PG 26-2, or tank mixed with PG 26-2 under different spray volume conditions against 3-4 leaf stage of barnyardgrass

Treatment	Spray volume (l/ha)	% Control at 4 WAA: 60 (g a.i./ha)	120	240
Cyhalofop butyl (GFH-342)	250	70 (0.12%)	95 (0.24%)	99 (0.48%)
	500	58 (0.06%)	90 (0.12%)	100 (0.24%)
	1000	40 (0.03%)	83 (0.06%)	99 (0.12%)
Cyhalofop butyl (tank mix)	250	90 (0.1%)	98 (0.1%)	100 (0.1%)
	500	80 (0.1%)	96 (0.1%)	100 (0.1%)
	1000	67 (0.1%)	93 (0.1%)	98 (0.1%)
Cyhalofop butyl (alone)	250	0 (0%)	48 (0%)	88 (0%)
	500	0 (0%)	43 (0%)	85 (0%)
	1000	0 (0%)	23 (0%)	57 (0%)

Percent control ratings represent the average of 3 replications.
GFH-342: Cyhalofop butyl 10% EC containing PG 26-2 at 50%
Number in parenthesis indicates the concentration of PG 26-2 in the spray solution.
Plot size was 2 m by 2 m.

Rainfastness. In greenhouse, cyhalofop butyl 30% EC at 90 or 180 g a.i./ha with different concentrations of PG 26-2 in the spray solution was tested the influence of 5 mm simulated rainfall at 0, 1 or 4 hours after application on its efficacy against 4 leaf stage of barnyardgrass. Results showed that with the addition of PG 26-2 at 0.1-0.4% under spray volume 187 l/ha significantly increased the rainfastness of cyhalofop butyl at 90 or 180 g a.i./ha (Table 4).

Table 4. Efficacy of cyhalofop butyl 30% EC tank-mix with different concentration of PG 26-2 on 4 leaf stage of barnyardgrass as influenced by various rainfall timings of 5 mm simulated rainfall following application under greenhouse condition

Formulation	% PG 26-2	Rainfall timing (HAA)	% Control at 3 WAA 90 (g a.i./ha)	180
Cyhalofop butyl	0.4	No rain	100	100
		1.0	65	85
		4.0	93	98
	0.2	No rain	98	99
		1.0	57	82
		4.0	67	99
	0.1	No rain	98	99
		1.0	62	84
		4.0	87	99
	0	No rain	25	79
		1.0	22	43
		4.0	30	40

Percent control ratings represent the average of 3 replications.
Rainfall timing: Rainfall treatment started at 1 or 4 hours after application of the chemical (HAA)
Speed of rainfall was 5 mm rainfall over 5 minutes.

Cyhalofop butyl 10% EC pre-mix formulation containing PG 26-2 at 50% (GFH-342) was tested its rainfastness in dry direct seeded rice under field condition. Cyhalofop butyl was applied at 80 g a.i./ha with a spray volume 200 l/h, where concentration of PG 26-2 was 0.2%. This treatment demonstrated excellent rainfastness that gave 95-99% control on 4 leaf stage of barnyardgrass at 4 WAA when 5, 10 or 20 mm simulated rainfall was sprayed not less than one hour after chemical application (Table 5).

Table 5. Efficacy of cyhalofop butyl 10% EC at 80 g a.i./ha with PG 26-2 at 0.2% on 4 leaf stage of barnyardgrass as influenced by various simulated rainfall rates and timings following application under field condition

Chemical	Rainfall rate (mm)	Rainfall timing (HAA)	% Control at 4 WAA
Cyhalofop butyl	20	0	80
(GFH-342)	20	1	95
	20	2	98
	20	4	98
	10	0	73
	10	1	97
	10	2	98
	10	4	98
	5	0	80
	5	1	97
	5	2	98
	5	4	99
	No rain		99

Percent control ratings represent the average of 3 replications.
GFH-342: Cyhalofop butyl 10% EC containing PG 26-2 at 50%
HAA is stand for hours after chemical application.
Speed of rainfall was 5 mm rainfall over 15 minutes.
To make PG 26-2 at 0.2% in the spray solution 200 l/ha spray volume was adopted.

Safety on rice. Cyhalofop butyl 30% EC single application at rates of 60 to 960 g a.i./ha was tested its phytotoxicity against 6 leaf stage of transplanted Japonica rice. No phytotoxicity was observed on all the treatments up to 4 WAA (Table 6).

Table 6. Phytotoxicity of cyhalofop butyl 30% EC agaisnt 6 leaf stage of transplanted Japonica rice

Chemical	Rate (g a.i./ha)	% Injury at 4 WAA % PG 26-2 0	0.1	0.4
Cyhalofop butyl	60	0	0	0
	120	0	0	0
	240	0	0	0
	480	0	0	0
	960	0	0	0

Percent injury ratings represent the average of 3 replications.
Rice variety is Japonica rice of TN 67.
Spray volulme was 500 l/ha and plot size was 2 m by 2 m.

Weed control spectrum. Cyhalofop butyl 30% EC with or without PG 26-2 at 0.1% concentration in the spray solution was tested their efficacy and phytotoxicity on 4 leaf stage of barnyardgrass and Henry's crabgrass (DIGAD), 4.2 leaf stage of red sprangletop (LEPCH) and 4.5 leaf stage of goose grass (ELEIN) in dry direct seeded Japonica rice. Results showed that among those 4 weed species mentioned above, goose grass and red sprangletop were most sensitive to cyhalofop butyl followed by barnyardgrass. Henry's crabgrass was most tolerate to cyhalofop butyl. PG 26-2 added into the spray solution at 0.1% enhanced the efficacy of cyhalofop butyl at 150 g a.i./ha against Henry's crabgrass and barnyardgrass (Table 7). No phytotoxicity on rice was observed in plot treated with cyhalofop butyl at 300 g ai/ha with the addition of 0.1% PG 26-2 (the highest rate tested) up to 4 WAA.

Table 7. Efficacy and phytotoxicity of cyhalofop butyl 30% EC with or without 0.1% PG 26-2 against grasses in dry seeded Japonica rice at 4 WAA

			% Control				% Injury
Chemical	Rate	PG 26-2	ECHCG	DIGAD	ELEIN	LEPCH	ORYSA
	(g a.i./ha)	(%)	LF = 4	4	4.5	4.2	3
Cyhalofop butyl	300	0.1	99	98	99	99	0
	300	no	99	90	99	99	0
	150	0.1	98	93	98	100	0
	150	no	87	43	97	99	0

Percent control ratings represent the average of 3 replications
LF is stand for leaf stage.
Plot size: 2 m by 2 m

Overall conclusions: Foliar spray of cyhalofop butyl with PG 26-2 is a super method for grass control in rice that provide reliable efficacy with flexibility in application under a variety of conditions; without any phytotoxicity to both transplanted and direct seeded Japonica rice.

TRINEXAPAC-ETHYL, A NEW PRODUCT FOR VEGETATION MANAGEMENT IN ZOYSIA TURF AND LODGING PREVENTION IN TRANSPLANTED RICE IN JAPAN

Shiaki Murakami, Akinori Nakamura, Hiroko Nishino and Jean-Louis Allard*
Ciba-Geigy Japan, Tokyo 105, Japan.
* Ciba-Geigy Ltd., Basle CH4002, Switzerland

Abstract. Trinexapac-ethyl is a new plant growth regulator discovered by Ciba-Geigy Ltd. under the code number of CGA163935. In Japan it is being developed under the code number of CG186. It belongs to the chemical class of cyclohexanediones. The compound is rapidly absorbed by leaves and inhibits the gibberellin biosynthesis from stage GA20 to GA1. This paper describes its use in Zoysia turf for vegetation management in golf courses and in transplanted rice for lodging prevention in Japan. Trinexapac-ethyl applied as a 25% wettable powder (WP25) at the dosage rate of 100 to 200 g a.i./ha was well tolerated by actively growing Zoysia turf. Mowed biomass (clipping) and mowing frequency were reduced by about 50% during the period of 4 to 6 weeks. Performance among field trials was uniform. In transplanted rice, trinexapac-ethyl WP25 applied at 20 to 30 g a.i./ha during stem elongation period (10 to 5 days before heading) reduced culm length by about 5 to 20 % and prevented the crop from lodging without negative influence on yield.
Key words. Trinexapac-ethyl, CGA163935, CG186, Turf vegetation management, Lodging prevention

Introduction

Mowing is an indispensable operation to manage and maintain the quality of turf in golf courses [7]. In Japan, mechanical mowing has become very costly. In addition, clipping disposal as well as operator's safety particularly in steep slope areas can be problematic. Plant growth regulators can be used to complement mechanical mowing; however, tolerance or consistency of inhibition has not been satisfactory to date [6]. Lodging prevention in cereals and in particular in rice is another area where plant growth regulators can be used [5]. In Japan, lodging is one of the major challenges for rice farmers cultivating high-yielding varieties with good taste such as KOSHIHIKARI. Under situations with high lodging risk, agronomic measures to prevent lodging such as optimization of fertilization and water management can effectively complemented by a chemical agent to avoid qualitative and quantitative yield losses [5].

Trinexapac-ethyl {ethyl 4- cyclopropyl (hydroxy) methylene-3, 5-dioxocyclohexane carboxylate} is a new plant growth regulator discovered by Ciba-Geigy Limited under the code number of CGA163935 [2,4]. It belongs to the chemical class of cyclohexanediones and is characterized by foliar uptake [4] and inhibition of gibberellin biosynthesis from GA20 to GA1 [1]. It has been marketed in the USA for turf use as Primo™ and in Europe for cereals as Moddus™. In Japan it is being developed under the code number of CG186 for vegetation management of turf grass and for lodging prevention in rice. This paper describes its biological performance in these use areas in Japan.

Materials and methods

Turf

Small plot trials: Trinexapac-ethyl formulated as a 25% wettable powder (WP25) was sprayed at 100 to 400 g a.i./ha on established turf of manillagrass (*Zoysia matrella* Merr.) 2 to 3 days after mowing at 25mm height in early June in Takarazuka Premises of Ciba-Geigy Japan and Ono Experimental Station in Hyogo Prefecture. Application was made with a CO_2-pressured small plot sprayer at a spray volume of 1'500 l/ha. Plot size was 6 m^2 with 2 replications. Turf plant height was recorded periodically. Inhibition (%) was expressed as height reduction (based on new growth) in comparison to untreated control. Flurprimidol {α- (1-methylethyl) -α- [4 - (trifluoromethoxy)phenyl] -5- pyrimidine-methanol} WP50 applied at recommended rate was included as a standard.

Experience in golf courses: In 1993-4, 11 large scale field trials in rough of Japanese lawngrass (*Z. japonica* Steud.) and one in nursery of manillagrass were executed in golf courses in collaboration with Japan Association for the Advancement of Phyto-Regulators (JAPR). Trinexapac-ethyl WP25 was sprayed on established turf at a spray volume of 1'500-2'500 l/ha 2 to 5 days after mowing mainly in June. The turf on rough was mowed at 30 to 55mm height and managed according to the program of each golf course. The turf on nursery was mowed at 15mm height and managed similarly to fairway of golf courses. The trials were carried out according to the JAPR guideline. Two different evaluation methods were applied depending on trial site; namely, 1) turf plant height was recorded periodically without mowing, and 2) mowing was made only when became necessary according to the course management program and clipping was weighed. The efficacy of trinexapac-ethyl was expressed as 1) % inhibition (see above) and 2) the first mowing date in DAA, mowing frequency and % clipping reduction based on accumulated mowed biomass, respectively.

Rice

In 1992 a field screening trial was executed at Ciba-Geigy Ono Experimental Station. Rice (*Oryza sativa* L., cv NIHONBARE) was machine-transplanted on June 12, 1992 and was grown as locally recommended. The heading time was August 19. Trinexapac-ethyl WP25 was over-the-top sprayed 20, 14, 9 and 4 days before the heading (DBH) by a CO_2-pressured small plot sprayer at a spray volume of 1'000 l/ha. Plot size was 4m^2 and each treatment was not replicated. At the time of harvest lodging degree was visually assessed on % scale (0: no lodging, 100: complete lodging) and length of the highest culm in a hill was recorded from 15 subsamples (15 hills). In 1994, 3 field trials were executed at trial sites of JAPR in Miyagi, Ibaragi and Fukuoka Prefectures. The rice variety planted was SASANISHIKI at Miyagi and KOSHIHIKARI at Ibaragi and Fukuoka. The rice crop was grown as locally recommended and the trials were carried out according to the JAPR guideline. Lodging degree was visually assessed on 0-4 index (0: no lodging, 4: complete lodging).

Result and discussion

Turf

Trinexapac-ethyl clearly inhibited plant height increase of zoysia turf at 100 to 400 g a.i./ha (Fig. 1). Its activity (% inhibition) of 50% or more lasted for about 30days at 100 g a.i./ha and 60 days at 200 g a.i./ha. Leaf color of the turf treated at these dosage rates became slightly and favorably more greenish and no other symptom was observed. At 400 g a.i./ha, it inhibited the turf growth completely for 42 days and later the turf grew slightly. Based on this result, we concluded that 100 to 200 g a.i./ha is a proper range of dosage rate of trinexapac-ethyl for further testing in zoysia turf in Japan.

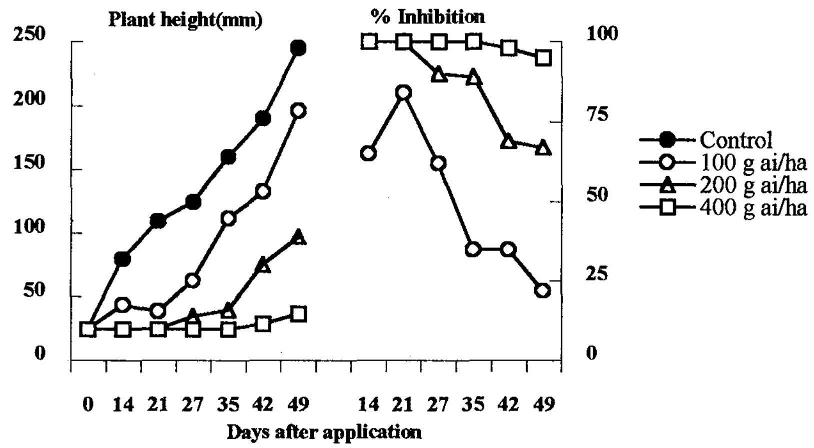


Fig. 1: Effect of trinexapac-ethyl on plant height increase of zoysia turf as affected by dosage rate

The activity (% inhibition) of trinexapac-ethyl among 7 trials was much more uniform than that of the standard, flurprimidol (Fig. 2). The uniform activity of trinexapac-ethyl, as compared to that of flurprimidol, can be due to its unique site of uptake[3] (namely, foliar) and is very useful feature of the product particularly for golf courses where soil condition differs from spot to spot even in a course. Under the rough situation in golf courses trinexapac-ethyl inhibited plant height increase by about 50% at 100 g a.i./ha and about 70% at 200 g a.i./ha for 24 to 40DAA (Table 1). The first mowing time was delayed by about 27 to 32days and mowing frequency in the first 42days after application was reduced substantially (Table 2). In brief, about 50% activity lasted for 4 to 6 weeks. As a result of reduced necessity for mowing, clipping amount was reduced by about 80% (Table 2). The product was well tolerated by zoysia turf except temporary discoloration in a trial which suffered from severe drought in 1994.

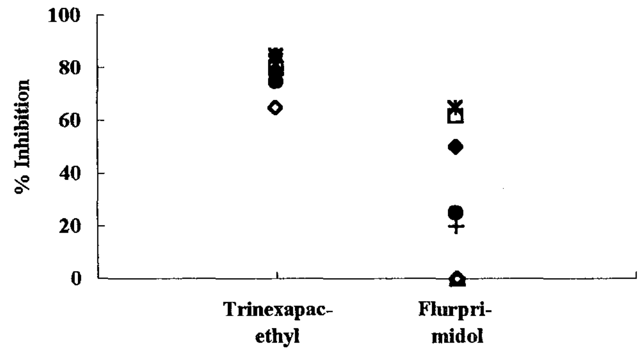


Fig. 2: Activity (% inhibition) of trinexapac-ethyl around 30DAA among 7 field trials (each dot represents each individula trial)

Table 1: Effect of trinexapac-ethyl on plant height increase of zoysia turf in rough of golf courses where turf was not mowed

Dosage g a.i./ha	% Inhibition Assessed around	
	24 DAA	40DAA
100	56%	52%
200	73	66
No. of trials	5	5

Table 2: Effect of trinexapac-ethyl on first mowing date, mowing frequency and % clipping reduction in zoysia turf in golf courses where the turf was mowed only when became necessary

Turf situation	Dosage g a.i./ha	First mowing date in DAA	Mowing frequency **	% clipping reduction**
		Average (range)	Average (range)	Average
Rough	100	51.3 (42-60)	0.3 (0-1)	72%
	200	56.5 (42-75)	0.3 (0-1)	80%
	Control	24.3 (13-30)	2.8 (2-4)	-
	No. of trials	4	4	3
Nursery (fairway)	100	21	2	-
	200	38	1	-
	Control	7	6	-
	No. of trials	1	1	-

*: In the period of 0 to around 42DAA, **: In the period of 0 t0 60DAA

In Japan, zoysia turf grows vigorously and consequently is to be mowed intensively in a rainy season between mid June and early July. During the rainy season, it is difficult to mow turf and collect clipping especially in rough on steep slope. Trinexapac-ethyl thus is a useful tool for improving turf management particularly in the rough situation in Japan. Mowing was made earlier and more frequently in the untreated control of the turf nursery managed similarly to fairway than that in the rough (Table 2). The efficacy expressed as the number of reduced mowing was also better in the nursery (fairway). This means the product is a useful tool for turf management also in fairway and its optimum rate is variable depending on requirement for turf quality and resulting magnitude of turf management practice such as fertilization and mowing height. Fine-tuning studies on the optimum rate in each turf situation are in progress. It has been reported that the product does not negatively affect divot recovery and does improve turf density and root mass in bermudagrass (*Cynodon dactylon* (L.) Pers.)[3]. Studies on these effects on zoysia turf in Japan are also in progress.

Rice

Trinexapac-ethyl prevented lodging of transplanted rice at every tested application time and dosage rate except at 15 g a.i./ha at 20 and 4 DBH in the screening trial (Table 3). At the effective timings and rates, it reduced culm length by about 5 to 30%.

Table 3: Anti-lodging activity of trinexapac-ethyl as affected by dosage rate and application time in a field screening trial in transplanted rice

Dosage g ai/ha	Application time (DBH)							
	% Lodging				Culm length			
	20	14	9	4	20	14	9	4
15	48%	5%	3%	13%	96%	94%	86%	93%
30	0	5	3	3	80	80	77	90
45	3	0	3	3	76	72	77	83
60	0	0	0	3	68	68	73	85
Control	40%				87.6 cm			

Table 4: Anti-lodging activity of trinexapac-ethyl in transplanted rice - an average of 3 trials throughout Japan

Application time (DBH)	Dosage g a.i./ha	Lodging index (0-4)	Culm length	Yield (Brown rice)
10-8	20	0.7	89%	107%
	30	0.5	87	106
6-4	20	0.6	88	105
	30	0.7	83	106
Control		2.7	77.2cm	50.8kg/a

From this result, we concluded that 20 to 30 g a.i./ha and 10 to 5 DBH are the optimum dosage rate and application time respectively. At JAPR trial sites from north to south of Japan, trinexapac-ethyl at 20 and 30 g a.i./ha applied at 10 to 4 DBH prevented lodging satisfactorily by reducing culm length by 11 to 17% (average) (Table 4) and 5 to 24% (range). It shortened the second internode most when applied at 6 to 4DBH and the second and third ones at 10 to 8DBH (data not shown). It did not affect yield (Table 4) and yield components (data not shown) at all. The product can be applied at a relatively late timing (10 to 5DBH) when the risk of lodging can be well predicted. Further trial work is in progress on application times and in wide range of geographical areas.

Conclusion

Trinexapac-ethyl is a unique and useful product for vegetation management in zoysia turf in Japan because of the high consistency of its efficacy and good turf tolerance as well as its low dosage rate and favorable environmental behavior. It will also contribute to profit-oriented rice farming because it can effectively complement costly agronomic practice to prevent lodging.

Acknowledgment: We wish to thank JAPR and the golf-course superintendents for their kind collaboration and fruitful discussion.

References

1. Adams, R., E. W. Weiler, E. Kerber, K. Pfister and M.-P. Schär (1991): Studies on the action of the new growth retardant CGA163935. Proc. 1991 British Crop Protection Conference - Weeds. 1133-1138
2. Amerein, J., J. Rufener and M. Quadranti (1989): The use of CGA163935 as a growth regulator in cereals and oilseed rape. Proc. 1989 British Crop Protection Conference - Weeds. 89-94
3. Ciba-Geigy Corporation, Turf and Ornamental Department: Technical bulletin for Primo®. Greensboro, NC, USA (1992)
4. Kerber, E., G. Leypoldt and A. Seiler (1989): CGA163935, A new plant growth regulator for small grain cereals, rape and turf. Proc. 1989 British Crop Protection Conference - Weeds. 83-88
5. Komatsu, Y. (1987): Characteristics and problem of anti-lodging agents. Shokucho, **21**, No. 7, 2-8 (in Japanese)
6. Nakamura, N. : "Growth retardants". In "Zoysiagrass" ed. N. Nakamura, Soft-Science Inc., Tokyo, pp97-99. (1993) (in Japanese)
7. Ohkubo, M. : "Turf management". In "Turf and turf grass" ed. K. Ebara and F. Kitamura, Soft-Science Inc., Tokyo, pp175-182. (1977) (in Japanese)

Halosulfuron-methyl- a New Herbicide for Control of *Cyperus rotundus* in Sugarcane, Maize, Turf and Cotton.

A.J. Somervaille, N.M.Tydens and B.J.Arnst*
Monsanto Australia Limited, 600 St Kilda Rd, Melbourne,3004, Australia

Abstract. The herbicide Halosulfuron-methyl was evaluated in 96 experiments from 1988 until 1994 as a broadcast post-emergence treatment for the control of *Cyperus rotundus* in warm season turf, sugarcane, maize and as a directed or shielded treatment in irrigated cotton. Post-emergence treatments in the range 50 to 100gai/ha including a non ionic surfactant provided good (>75%) to excellent (>85%) control of *Cyperus rotundus* for 2 to 4 months following application. Halosulfuron-methylgenerally did not have any pre-emergence activity on *Cyperus rotundus* and longer term control of this weed required repeat application to shoots, particularly those emerging from dormant tubers. Halosulfuron-methyl showed no phytotoxicity at rates up to 200gai/ha on warm season turf cultivars including *Cynodon dactylon* and hybrids, *Digitaria didactyla, Stenotaphrum secundatum, Dactyloctenium australe* and *Axonopus affinis.* Post-emergence applications in sugarcane showed no phytotoxicity at rates up to 150gai/ha with only a 5% reduction in sugar yield noted in one experiment with a treatment of 300gai/ha. Treatments up to 100gai/ha applied post-emergence in maize showed only occasional transient yellowing. Selectivity of treatment in cotton was effectively obtained with one application using a shielded sprayer when plants were a minimum of 20cm in height.

Key Words. Sempra, halosulfuron-methyl, *Cyperus rotundus*, nutgrass, sugarcane, turf, cotton, maize.

INTRODUCTION

Nutgrass, *Cyperus rotundus,* is a significant weed of amenity areas, especialy turf, as well as number of key crops including sugarcane, cotton and maize in the Eastern and Northern regions of Australia. Infestations of sedges ingeneral detract from the aesthetic appearance of amenity areas and interferes with the "trueness' of playing surfaces on golf courses and sportsfields.

Both Charles 1991 and Hazard and Palu 1986 have documented nutgrass as a serious weed of cotton in Queensland and New South Wales. While the effect on cotton yield is not well documented Charles (pers comm) has indicated lint reductions of between 320 to 460kg/ha. where severe infestations have been measured.

Nutgrass infests sugarcane throughout the cane growing areas along the Eastern seaboard of Australia. Infestations vary in their abundance across the region being most widespread in the central Mackay region where up to 30% of planted land is possibly infested.

Control of nutgrass relys on both chemical and cultivation methods, often in combination. In turf, commercial formulations of DSMA and MSMA have been used with limited success and often turf injury. MSMA is more commonly used in cotton but is reliant on ideal treatment conditions to achieve reasonable levels of suppression. The sodium salt of 2,4-D is widely used in sugarcane giving suppression up to six weeks though in many cases short term dessication of leaf material is followed by much more rapid recovery. Fallow treatments of Roundup (glyphosate) have been utilised successfully by some growers to reduce infestations in following crops.

Sempra [methyl 3 - chloro-5-(4,6-dimethoxypyrimidin-2-ylcarbomylsulfamoyl)-1-methylpyrazole-4-carboxyllate] common name halosulfuron-methyl is a sulfonyl urea herbicide discovered by Nissan Chemical Industries Limited and developed by Monsanto Company (Suzuki et al., 1991). Sempra acts in susceptible plants by inhibition of the acetolactosynthase (ALS) enzyme involved with the synthesis of plant protein.

Commencing in 1988 Monsanto Australia Ltd began a field evaluation program to determine the effectiveness of Sempra to control nutgrass. This program culminated in the commercialisation into turf in 1994 and expected release into cotton and sugarcane during 1995. This paper summarises the results of 96 experiments conducted during this period.

MATERIALS AND METHODS

Herbicide treatments in small plot trials were applied with a compressed gas sprayer attached to a hand held spray boom equipped with flat tapered nozzles operated at a pressure of between 150-250 kPa delivering 70-170 l/ha of carrier. A range of commercial equipment was also used depending on the use situation, including tractor mounted boom sprayers with twin floodjets mounted on "irvin" legs, shielded sprayers and high volume knapsack or handgun.

Treatments were applied to plots varying in size from between 14 and 36 square meters with three or four replications with the exception of larger scale user demonstration sites.

In all experiments Sempra was applied in combination with a 60% ai w/v nonylphenolethoxylate surfactant at a rate of either 0.2 or 0.3% in spray solution.

Assessments of phytotoxicity to nutgrass included a subjective assessment of brownout prior to 28 days after treatment (DAT) followed by a percentage figure for control.

RESULTS AND DISCUSSION

Symptoms of phytotoxicity following the application of Sempra to nutgrass were comparatively slow to develop taking the form of cessation of new growth and gradual yellowing reaching a peak one to two months following treatment. Symptom development occurred quicker under higher temperatures and where adequate moisture was present. In experiments where less than 80% of weed control was reported this often reflected the appearance of new shoots from tubers which were not represented by above ground shoots at the time of application.

Turf

A single application of 50 or 100 gai/ha Sempra provided commercially acceptable (>80%) control of nutgrass in 9 of 13 experiments 28 to 63 days after treatment. In the longer term (80 to 154 days after treatment) the lower rate provided commercially acceptable control in only 3 of 9 experiments while the 100gai/ha rate provided >80% control in 6 of 9 experiments. Sequential treatments of 50 and 100gai/ha provided commercially acceptable control in 4 of 5 and 6 of 6 experiments respectively with 80 to 100% shoot reduction 63 to 154 days after treatment (Figure 1). Sempra applied at 100gai/ha provided >90% control 42 to 65 days after treatment in 4 commercial use demonstrations established on turf farms and golf courses.

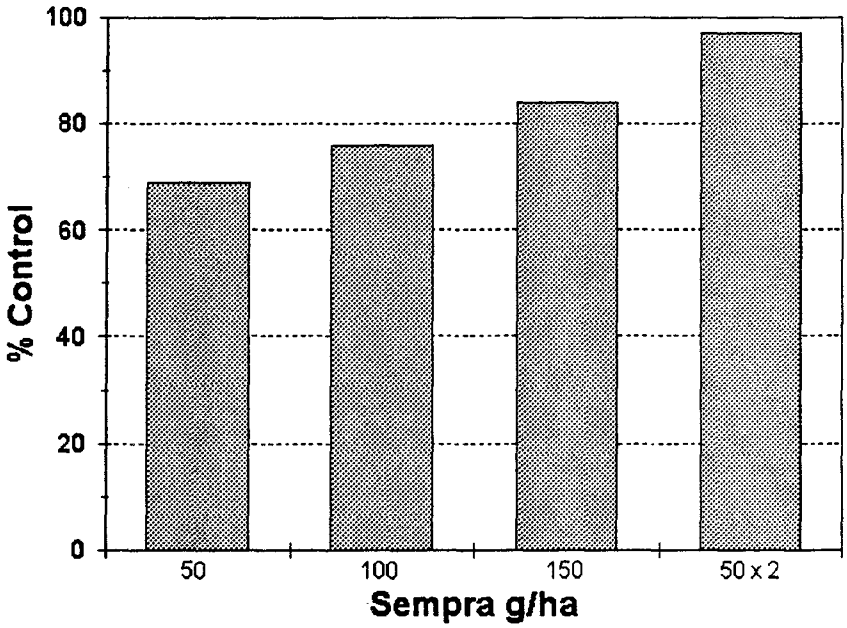


Fig 1. Nutgrass control in turf, 4-5 months after intial application, with single and sequential doses of Sempra.

In some experiments, reemergence of new unaffected shoots ocurred within 6 weeks of application while reemergence of shoots from incompletely controlled plants ocurred within this time though often these were stunted and spindly. Field and greenhouse studies conducted in USA indicate that while applications of 70gai/ha of Sempra kill entire basal tubers and connected tillers, only a sublethal dose was tanslocated to connected tubers (Jackson et al., 1993). This reinforces the results we have obtained that show that a sequential application of Sempra will be required for season-long control (Fig 2.).

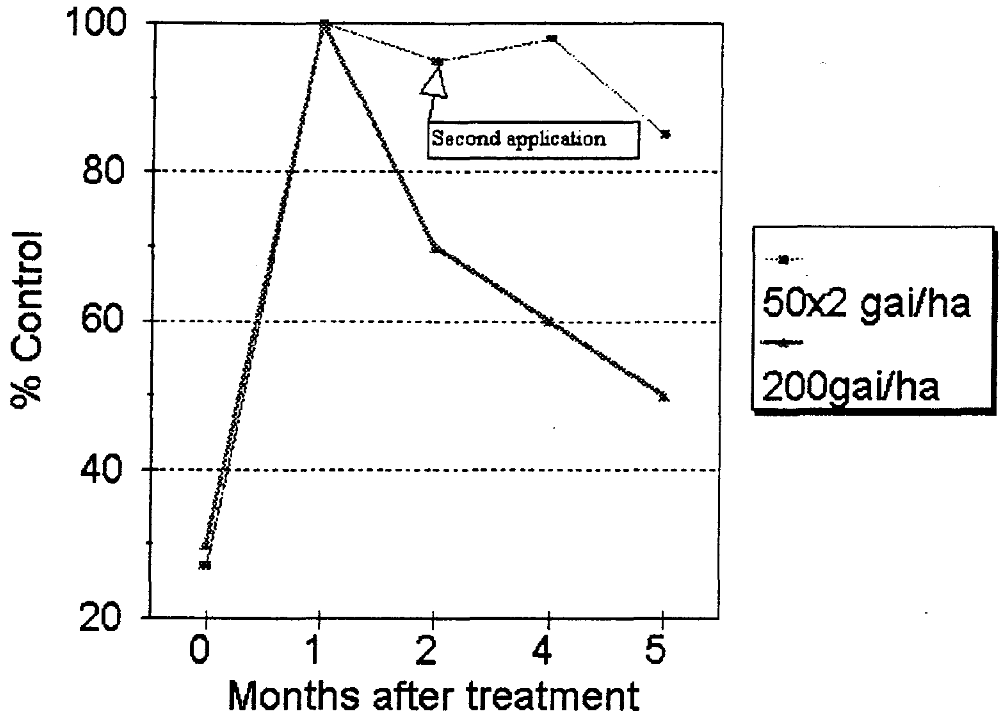


Fig2 Sempra application to nutgrass in turf showing length of control effect by sequential applications

Sempra treatments did not exhibit phytotoxicity in any experiment on established turf at rates up to 200gai/ha including a range of species secreened in a turf phytotoxicity screen . This finding is in agreement with US studies which evaluated turf tolerance in a range of cool and warm season turf species at rates up to 280gai/ha (Travers et al., 1993). Selectivity was assessed in Australia included a number of couch cultivars such as Greenlees Park, Wintergreen and Bermuda 328, common couch, Queensland Blue couch (*Digitaria didactyla*), Durban grass (*Dactyloctenium australe*), Buffalo grass (*Stenotaphrum secundatum*), kikuyu (*Pennisetum cladestinum*), Narrow leaf carpet grass (*Axonopus affinis*) and Broadleaf Carpet grass (*Azonopus compressus*). Cool season species including bentgrass and perennial ryegrass (K. Fallow pers. comm.) have not shown any phytotoxicity following treatment up to a maximum test rate of 100gai/ha.

Cotton.

In 24 trials it was clearly shown that the actual length of control was dependent on the extent of emergence at application. Higher levels of control (90%) up to 128 DAT were measured under light infestations while under heavy infestations initial control was high but in time was reduced as new plants emerged.

The results in Figure 3 have been averaged for the 25 trials and a standard deviation and 95% confidence interval calculated. These results clearly show a dose response with 37.5 gai/ha being the threshold rate. Rates above 150gai/ha do not improve the level of control appreciably above 80%. In these trials the standard MSMA provided an average of only 30% control.

To better treat heavy infestations of nutgrass four trials applied Sempra sequentially, approximately one month after first application. In 3 out of 4 experiments the additional application extended the commercial (>80%) level of control for over 2 months. The need for sequential applications in cotton is more likely where the first application is applied early to allow the crop to establish leaving a greater period of time to elapse before canopy closure.

The benefit of nutgrass control with Sempra was clearly seen in those experiments taken to yield. Results from one trial, Fig 4., show lint yields in tonnes per hectare. All herbicide treatments including the standard improved yields. As with control assessments the dose response flattened above 50gai/ha.

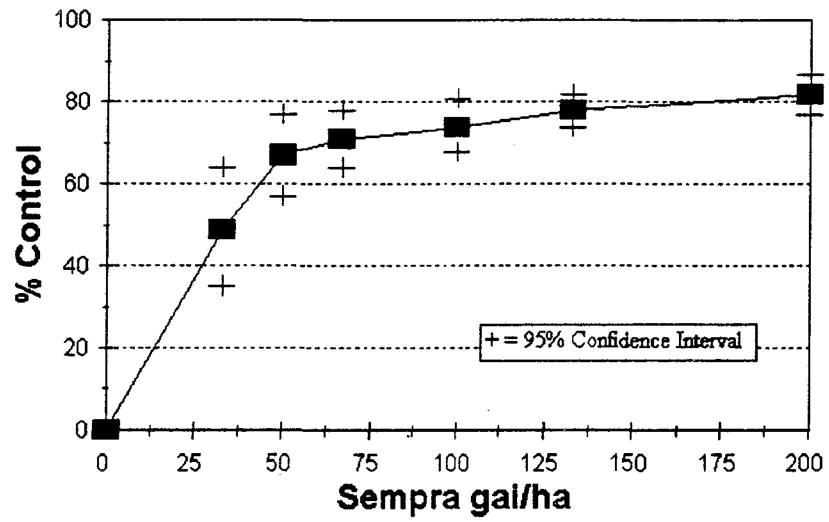


Fig 3. Nutgrass control in cotton showing dose response curve

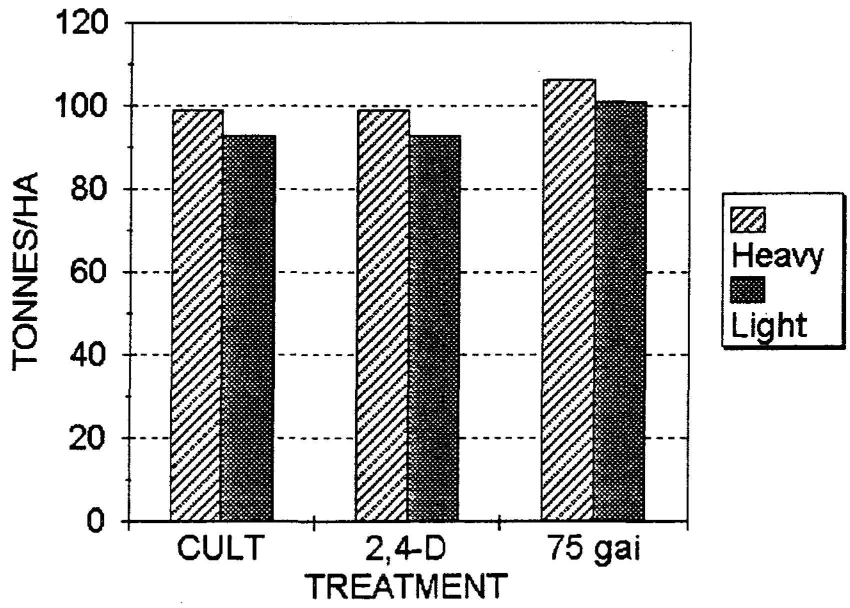


Fig 4. Sugarcane yields reflecting control of nutgrass with Sempra under heavy and light infestations.

Observations on phytotoxicity were made in 18 of the 24 efficacy trials where Sempra was applied by a directed or shileded sprayer. Sempra injury was noted as yellowing of leaves about 10 days after treatment disappearing by 30 dats after treatment. Stunting of the crop also occurred where direct contact was made with the cotton, however in most cases these stunted plants fully recovered.

Sugarcane

Sempra provided commercially acceptable control of nutgrass (>80%) one to three months after application in 7 and 16 of 24 experiments for 50 and 100 gai/ha respectively. A commercially acceptable level of suppression (70-79%) was provided in a further 12 and 5 experiments for these treatments. A lower rate of 37gai/ha also provided commercially acceptable suppression in 4 of 6 experiments. In contrast, a standard treatment of 2, 4-D Sodium salt provided >80% control in only 1 of 15 experiments.

As with turf and cotton sequential treatments applied 37 and 64 days after initial treatment provided excellent control up to 126 days from treatment. During 1994 two trials were taken to harvest to establish the effect on yield of controlling nutgrass under both light and high levels of infestation.. Under both regimes the advantage of nutgrass control with Sempra was clearly shown resulting in a significant yield increase over untreated (cultivated) and the standard 2,4-D (Fig 5).

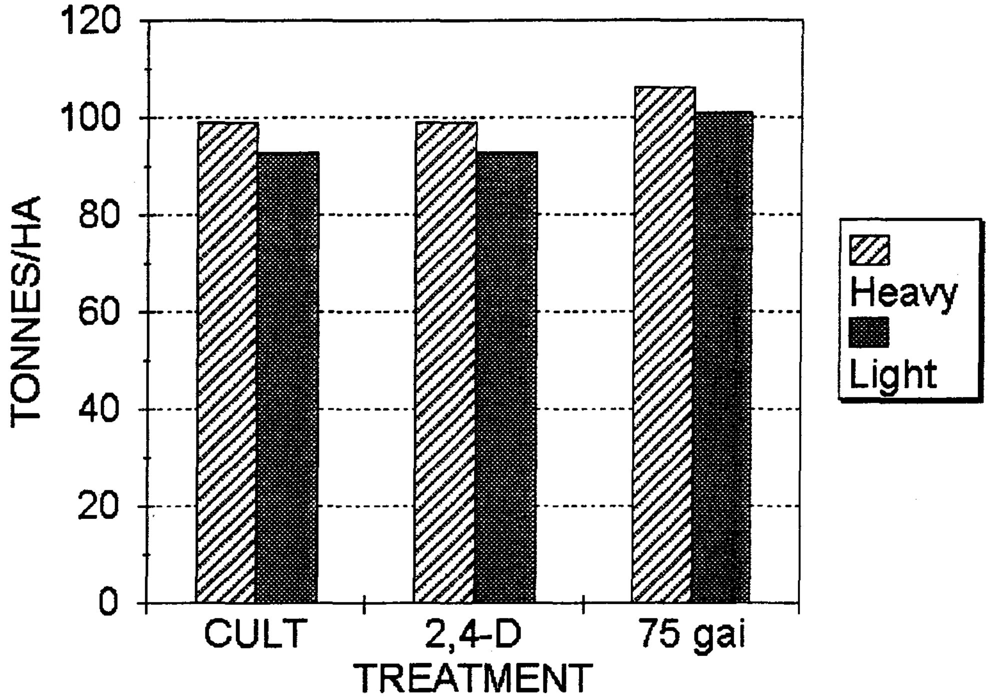


Fig 5. Sugarcane yields reflecting control of nutgrass with Sempra under heavy and light infestations.

Observations on phytotoxicity were made in 20 of the 26 efficacy trials, including eleven different cane varieties in both plant and ratoon situations, encompassing wet and dry conditions over five seasons. There was no growth reduction following application of rates up to 200 gai/ha. In two trials some yellowing (6-10%) was observed early after treatment.

Maize

In five trials conducted in maize crops Sempra applied at rates of 150gai/ha gave similar results to those noted above for cotton and sugarcane. Selectively in maize was generally good with only slight yellowing noted 10-20 DAT.

Overall Sempra has been provided excellent control of nutgrass when applied at rates from 50gai/ha in all use situations.. Where infestations are heavy or in turf situations the benefit of a sequential application have been clearly shown.

References

CharlesG. 1991 A grower survey of weeds and herbicide use in the NSW cotton industry. Aust. J Exp Ag 1991,31,387-92

Jackson.N.E.,J.N.Dutt,and J.M.Goette, Control of purple and yellow nutsedge in turfgrass with MON-12000. International Turfgrass Society Research Journal 7. RN Carrow, N E Christians, R C Shearman (Eds). Intertec Publishing Corp., Overland Park, Kansas. 1993 pp 269-272

Suzuki.K., S.Nawamaki, S.Watanabe and B Wells, NC-319- A new herbicide for control of broadleaved weeds and Cyperus spp. Brighton Crop Protection Conference- Weeds.31-37

Travers. J.N.,N.E.Jackson, K.D.Jolly and D.R.Williamson . Tolerance of MON-12000 herbicide to warm and cool season turf-grasses. International Turfagrass Society Research Journal 7. R N Carrow, N E Christians, R C Shearman (Eds). Intertec Publishing Corp., Overland Park. Kansas 1993 pp 262-268.

Acknowledgements

The authors wish to acknowledge the cooperation of turf farmers, superintendandants and curators, cotton and sugar growers and the BSES for facilitating the establishment of experiments and demonstration plots.

Possible Utilization of Plants And Allelochemicals For Weed Control

Kil-Ung Kim*

Dept. of Agronomy, Coll. of Agri., Kyungpook National Univ.
Taegu 702-701, Republic of Korea

Abstract. The potentials of 109 weed species to be used as health vegetables and medicinal herbs have been suggested in Korea. Plants secrete a wide spectrum of chemical substances including the products of basic or secondary metabolism. There are a large number of known secondary metabolites produced from the metabolic pathways from some biogenetic precursors: about 7000 alkaloids from amino acids, about 5000 terpenoids from melvalonate, about 1000 flavonoids and 500 simple phenylpropanes from cinnamic acid, and more than 1350 polyketides and polyacethylenes from acetyl CoA. Allelophatic potential has been identified in a large number of weed species including some of world's worst weeds : barnyardgrass (*Echinochloa* spp.), ragweed parthenium (*Ambrosia* spp.), quackgrass (*Agropyron repense*), johnsongrass (*Sorghum halepense*), canada thistle (*Cirsium arvense*), giant foxtail (*Setaria faberi*), some sedge (*Cyperus* spp.), *Amranthus* spp. and *Chenopodium* spp., and in a large number of crop residues such as barley, wheat, rye, oat, sunflower, sorghum, mungbean and alfalfa. The most successful use of allelochemicals in weed control has been management of selectively toxic plant residues. Commonly known allelochemicals are phenolic compounds like coumarins and phenolic acids, quinones or alkaloids. Terpenoid family and fatty acids in terms of their higher bioactivity are the most promising candidates for natural herbicides structure model. Factors affecting the amounts of allelochemicals produced by plants are not well studied, although stress environment (moisture. temperature, nutrient, herbicide and disease stresses etc.) may enhance allelochemical production. One of the greatest difficulties in developing allelochemicals from plant sources is assaying them precisely. Thus the continued development of new assays and screening tools will help in identifying novel allelochemicals from plants.
Key words. secondary metabolites, allelopathy, allelochemicals, terpenoid, fatty acid.

Introduction

Valuable chemical compounds are present in virtually in all plants and in many tissues, including leaves, stems, flowers, fruits, and seeds so on. Under certain conditions, plants secret a wide spectrum of chemical compounds including the product of basic or secondary metabolism into the environment in sufficient amounts with enough persistance to influence on a neighboring or successional plant. Secondary compounds of plants and microorganisms have been known to be toxic to weeds, insect or microbial. Such compounds have been used either in their natural or modified form, as pesticides for many years.

There is increasing interest in use of naturally-produced compounds because of inherently less toxic and environmentally benign than synthetic chemicals. There have been many reviewed papers regarding allelochemicals from plants as herbicides (Putnam 1988, 1988, Duke et al. 1995, Einhellig 1995, Macias 1995). Therefore, this paper will deal briefly with possible utilization of plants, especially weed species in Korea and potential of allelochemicals for weed control with some researches done in and out of Korea.

Possible Utilization of Plants

About 351 weed species in 66 families are listed in Weed Flora of Korea. Among those weeds, 20 species have been used as folk medicines and 12 species as health vegetables. In addition, out of 351 weed species, 109 species in 50 families have been reported to have potentials to be used as medicinal herbs in Korea (Table 1) (Chi 1991). The chemical components and uses of those weeds are present in Table 1, with usuable parts of plant.

About 1900 weed species are listed to occur in the mainland China. Out of them, about 500 species are common weeds and among them, 208 species occur in agricultural fields. Only about 30 species are the most noxious and difficult to control (Li 1991). Li (1995) proposed potentials of nine weed species as botanical resources having the value of medicinal herbs. They are chickweed (*Stellaria media* (L.) Cyr.), dandelion (*Teraxacum mongolicum* Hand.-Mazz.), plantain (*Plangago asiatica* L.), shepherd's purse (*Capsella bursa-pastoris* (L.) Medic.), sorrel (*Rumex acetosa* L.), sow-thistle (*Sonchus brachyotus* D.C.), thorn-apple (*Datura stramonium* L.), cleavers (*Galium aparine* L. var. *tenerum* Gren. et Godr.), burdock (*Arctiuim lappa* L.), cornflower

(*Centaurea cyanus* L.), and horsetail (*Equisetum arvense* L.).

As indicated in the Table 1 and utilization of weed species in Korea and China, weeds are very important to almost every one of us, in terms of crop-weed competition, preservation for botanical resources and for a better ecological environment. Further studies will shed more light on the possible utilization of weed species because they are good reserves for human life.

Allelopathy and Allelochemicals

Allelopathy. The term "allelopathy" was first used by Molish (1937) to refer to biochemical interactions between all types of plants including microorganisms. The definition of allelopathy has not been static and the term continues to applied in slightly different ways (Einhellig 1995). However, most of the researchers in the field of allelopathy have adopted Molish's original definition.

Allelochemicals. Chemicals that impose alleleophatic influences are called allelochemicals. Several hundred different allelochemicals released from plants and microbes are known to affect the growth or aspects of function of the receiving species. There were a large number of known secondary metabolites which were produced from the metabolic pathways from some biogenetic precursors: about 7000 alkaloids from amino acids, about 5000 terpenoids from melvalonate, about 1000 flavonoids and 500 simple phenylpropanes from cinnamic acid, and more than 1350 polyketides and polyacethylenes from acetyl CoA (Roshchina et all. 1993).

Chemical origin of allelochemical. Alleleochemicals reported from higher plants are mostly secondary compounds that arise from either the acetate or shikimic pathways, or their chemical skeletons come from a combination of the two origins (Einhellig 1995). Wittaker and Feeny (1971) classified into five groups: phenylpropanes, acetogenins, terpenoids, steroids, and alkaloids. However, Rice (1984) presented 14 categories of allelopathic compounds plus a miscellaneous group. There is an extensive diversity of structures among the several hundred known allelochemicals although some commonality in the primary pathways of their biosynthesis is evident (Einhellig 1995).

Release of Allelochemicals. Higher plants regularly release organic compounds by volatilization from their surfaces and through leaf leachates and root exudates. Allelochemical trasnsfers from one higher plant to another in a given community can be either through volatiles, aqueous leachates, or various exudates.

The source of allelochemicals in agroecosystem may be either the crop, weeds, or microorganisms of the decomposition processes. Weeds are always present in agricultural fields in association with crops (Putnam and Weston 1986).

Factors Affecting Production of Allelochemicals。 There are many factors affecting release of allelopathic agents from plants. Allelopathy is tightly coupled with competition for resources and stresses from disease, temperature, extreme moisture deficit and herbicide (Einhellig 1995). Production of allelochemicals such as coumarins (scopoletin, scopolin), in tobacco and sunflower increased in response to nutrient, temperature, herbicide and radiation stresses. Barley alkaloids increased when plants were grown under high temperature (Hanson, 1983). A variety of of phenolics increased in plant damaged by insect or disease (Sembdner et al. 1993). It is known that temperature, moisture, nutrient, herbicide and disease stresses are common in natural environmental conditions. Stresses such as moisture and temperature conditions not only directly affect plant growth, they may enhance allelochemcal production which subsequently impacts plant growth of associated plants. Thus, it seems that these collective stresses may interact in additive, synergistic, or antagonistic ways in production of alleleochemicals in plants.

Allelochemicals for Weed Control

Allelochemicals may contribute to controlling weeds either through the use of allelopathic plants or their isolated products. The most promising use of allelochemicals in weed control has been management of selectively toxic plant residues. Some of major crops such as barley, rye, oat, sunflower, sorghum and cucumber etc. have been determined to produce allelochemicals which can affect weed growth and influence next crops. For example, residues of baley, wheat and rye have controlled weeds effectively in a variety of cropping systems (Putnam 1988, Kim et al. 1987). Thus far, the phenolic compounds in plant residues have been intensively studied to evaluate their allelophatic potential as protective agent to control weeds, insects and fungi (Court et al, 1982, Beart et al, 1985, Rice 1984, Kim 1987).

There is a comprehensive review regrding allelopathy in Korea presented by Kim (1993), citing all the works done within Korea, and stressing that the work in Korea on allelopathic potential as a mean of controlling weeds has been thus far focused on phenolic compounds either from crop residues or from a number of upland weeds. The need of in-depth chemical studies on allelopathic sustances rather than phenolic compounds was stressed in his review. Development of allelochemicals from plant sources is still at the infant stage. There are many things to do along this line in years to come.

A number of weeds also interfered with crop growth through chemical released from their residues. Weed species that show allelophatic potential have been reported in some of world's worst weeds such as barnyardgrass, ragweed parthenium, quackgrass,, johnsongrass, canada thistle, and giant foxtail etc. (Einhellig 1995), and some other species like *Amaranthus* spp. and *Chenopodium* spp. etc..

There are excellent reviews about the potential use of allelochemical as herbicides from plant sources (Putnam 1988, Duke et al. 1995, Einhellig 1995, Macias 1995). Macias (1995) reduced 13 classes of alleochemicals reported by Rice (1984) to seven classes which seem to be the most promising allelochemicals; simple acid as ethyl propionate, polyacetylenes as trans-DME, long chain fatty acids as myristic acid, monoterpenes as tujone, sesquiterpene lactones as annuolide A, and tritrpenes as messagenin. These families have been discarded as priori as potential natural herbicide due to low solubility in water. Water solubility of some of them, for example, monoterpenes, was greatly improved to be enough as potential natural herbicide.

Bioactivity acceptable as allelochemicals. Allelochemical activity is normally tested at ranges between 10^{-4}-10^{-9} M ca. 0.1-10^{4} ppb. Good candidates for natural herbicide model seems to be the range between 10-10^{3} ppb ca. 10^{-5}-10^{-7} M. Thus, it seems that phenolic compounds as benjoic derivatives, coumarines, flavonoids, alkaloids and quinones that has been demonstrated to be active at ranges between 10^{-2}-10^{-5} M ca. 10^{3}-10^{6} ppb are not suitable candidates as natural herbicides (Macias 1995).

Figure 1. Bioactivity range of allelopathic agent families from higher plants (adapted from Macias 1995).

```
    10^-2     10^-3     10^-4     10^-5     10^-6    10^-7     10^-8      10^-9 (M)
    10^6      10^5      10^4      10^3      10^2     10        1          0.1 (ppb)
=====================================================================================
         |        |     ************ Simple esters|          |          |
         |******** Alkaloides           |         |          |          |
         |        | ***************|Polyacetylenes|          |          |
 Cianhydrines *****    |****** |Sulphur compounds             |          |
         |        |    |       |   *** Fatty acids            |          |
         |     ****** Quinines        |           |          |          |
 ****************** Benzoic acid derivatives|                |          |
 ************************** Cinnamic acid deritives          |          |
         |        | *********** Coumarins  |      |          |          |
         |        |     ********** Flavonoids     |          |          |
         |       ****************************|Monoterpenes   Sesquiterpenes^a
         |       *************************Sesquiterpenes     |*******   |
         |        |         |  Sesquiterpene lactones^a  ***********    |
Sesquiterpene lactones |*****************************************       |
         |        |    ******** Diterpenes|        |         |          |
         |        |  ******************************************** Triterpenes
```

[a] Bioactivity range over *Striga leutea* Lour. F

Figure 1 shows bioactivity range of allelopathic agent families isolated from higher plants in which activity varies greatly depending on class of allelochemicals (Macias 1995). From these data, it can be concluded that the most potential natural allelochemicals in terms of bioactivity are terpenoids: monoterpenes. sesquiterpenes, sesquiterpene lactones and triterpenes, and fatty acids with activity range of 0.25-10^{5} ppb, rather than the traditionally considered phenolics, quinones or alkaloids (Macias 1995). Terpenoids and fatty acids will receive a great attention in years to come in development of natural products as herbicides. Along with development of allelochemicals, one of the most difficulties to overcome is to assay them precisely, either allelopathic compounds to be used directly as herbicides or to be used as leads for new chemical familiies of herbicides.

References

Beart, J. E., T. H. Lilley and E. Haslami. 1985. Plant polyphenol-secondary metabolism and chemical defence: some observations. Phytochemistry 24(1):33-38.

Court, W. A., J. M. Elliot and J. G. Hendel. 1982. Influence of applied nitrogen on the nonvolatile fatty and organic acids of flue-cured tobacco. Can. J. Plant Sci.62(2):489-496.

Chi, H. J. 1991. Korean weeds as valuable health vegetables and medicinal herbs. Korean J. Weed Sci. 11(5):113-120.

Duke, S. O. and H. K. Abbas. 1995. Natural products with potential use as herbicides p. 348-362 In Inderjit, K. M. M. Dakshini and F. A. Einhellig. Allelopathy. 1995 American Chemical Society.

Einhellig, F. A. 1995. Allelopathy: Current status and future goals. p. 1-25 In Inderjit, K. M. M. Dakshini and F. A. Frank. Allelopathy. 1995 American Chemical Society.

Hanson, A. D., K. M. Gitz, G. W. Singletary, T. J. Loland. 1983. Gramine accumulation in leaves of barley grown under high-temperature stress. Plant Physlol. 71:896-904

Kim, K. U., I. J. Lee, H. J. Jeong and D. S. Kim. 1987. Potential allelopathic substances identified from annual straws. Proc. of 11th Asian-Pacific Weed Science Society Conf. p. 303-310.

Kim, K. U. 1993. Integrated management of paddy weeds in Korea, with an emphasis on allelopathy. Food & Fertilizer Technology Center. Technical Bulletin 134:8-23.

Li, Y. H. 1991. Weeds as botanical resources with emphasis on the value of medicinal herbs. Korean J. Weed Sci. 11(5):107-112.

Macias, F A. 1995. Allelopathy in the search for natural herbicide model. p. 319-330. In Inderjit, K. M. M. Dakshini and F. A. Einhellig. Allelopathy. 1995 American Chemical Society.

Molish, H. 1937. Der Einfluss einer Pflanze die andere-allelopathic. Fisher, Jena. Outnam, A. R. 1988. Allelochemical from plants as herbicides. Weed Technology 2:510-518.

Putnam, A. R. and L. A. Weston. 1986. Adverse impacts of allelopathy in agricultural systems, p. 43-56 In A. R. Putnam and C. S. Tang. The Science of Allelopathy. John Wiley and Sons, New York.

Rice, E. L. 1984. Allelopathy. Academic Press, Orlando, FL. p. 266-291.

Roshchina, V. V. and V. D. Roshchina. 1993. In the excretory function of higher plants. Springer-Verlag. p. 5-9.

Sembdner, G and B. Parthier. 1993. The biochemistry and the physiological and molecular action of jasmonates. Annu. Rev. Plant Physiol. 44:569-589.

Whittaker, R. H. and P. P. Feeny. 1971. Science 171:757-767.

Table 1. List of Korean weeds to be used as valuable health vegetables and medicinal herbs.

Family name	Sci. name	Utilization	Components	Used part[1)]
Acalyphaceae	*Acalypha australis*	diuretic, antidiarrhea	alkaloid	Wp
Acantaceae	*Justicia prucumbens*	antimalaria jaundice	cistithine A-D	Wp
Agrimoniaceae	*Agrimonia pilosa*	antihemorrhagic antidiarrhea anthelmintic	agrimonolid	Rh
	Sanguisorba officinalis	antihemorrhagic	sanguisorbin	Rh
Alismataceae	*Sagittaria aginashi*	snake antidote		Wp
	Sagittaria trifolia	jaundice snake antidote		Wp
Alsinaceae (Caryopthyllaceae)	*Dianthus chinensis*	diuretic	saponin	If
	Gypsophyla paniculata	expectorant tonic	gypsogenin gypsogenic acid	Rt
	Melandryum firmum	lactagogue antihemorrhageic analgesic	saponin	Sd
	Stellaria medica	lactagogue antiinflammatory		Ls
Amarantaceae	*Achyrantis japonica*	diuretic	ecdysterone inokosterone	Rt
	Celosia argentea	tonic		Sd
Apiaceae	*Centella asiatica*	dermatological agent	asiaticoside	Wp
	Hydrocotyle maritima	antihemorrhagic		Wp
	Torillis japonica	antifungal	oadinen torilen	Sd
Araceae	*Pinellia ternata*	antiemetics		Bu
Boraginaceae	*Bothriospermum tenellum*	expectorant		Wp
	Trigonotis peduncularis	antidote		Wp
Brassicaceae (Cruciferae)	*Capsella bursa-pastoris*	antihemorrhagic diuretic	bursic acid	Sd
	Cardamin flexuosa	diuretic		Sd
	Lepidium apetalum	diuretic		Sd
Cannabinaceae	*Humulus scandens*	diuretic antidote	luteorin benzyl alchol	Ls
Cardulaceae	*Artemisia capillaris*	jaundice diuretic	capillen β-pinene 6,7-dimethyleculetin	Ls
	Artemisia vulgaris	antihemorrhagic	cineol α-thujon	Ls
	Bidens tripartita	anticonvulsion	flavonoid essential oil	Ls
	Carduss crispus	antirheumatic	acanthoidine	Wp
	Centipeda minim	rhinitis antidote	triterpenoid flavonoid	Wp
	Cephalonoplos segetum	antihemorrhagic hepatitis	flavonoid saponin	Wp
	Cirsium macckii	tonic diuretic antihemorrhagic	flavonoid	Wp
	Eclipta prostarata	antihemorrhagic	saponin	Ls
	Erigeron annus	antidote	pyromeconic acid	Wp
	Gnaphalium affine	antitussive muscle pain	flavonoid essential oil	Wp

Table 1. continued

Family name	Sci. name	Utilization	Components	Used part
Cardulaceae	*Helianthus tuberosus*	expectorant antitussive	inulin acantolactone	Rh
	Inula japonica	stomachics diuretic	inulicin britanin	Fl
	Siegesbeckia glabrescens var. asiatica	antipyretic	diterpenes	Wp
	Solidago virga-aura	analgesic antidote	flavonoid rutin	Wp
	Xanthium strumarium	rhinitis	xanthostrumarin	Fr
Cassiaceae	*Cassia nommame*	diuretic		Sd
Chenopodiaceae	*Chenopodium album*	stomachic tonic	betain leucin	Lf
	Kochia scoparia	diuretic tonic	harman harmin	Sd
Cichoriaceae	*Ixeris chinensis*	jaundice		Wp
	Ixeris sonchifolia	analgesic anticonvulsion		Wp
	Lactuca laciniata	antipyretic	lactucerin β-amylin taraxasterol	Wp
	Taraxacum platycarpum	antipyretic stomachic	taraxasterol	Rt
Commeliaceae	*Commelia communis*	antidiabetic		Wp
Convolvulaceae	*Calystegia japonica*	tonic	saccharide	Wp
	Cuscuta japonica	tonic		Sd
Crassulaceae	*Sedum sarmentosum*	hepatitis antidote	sarmentosin	Ls
Cyperaceae	*Cyperus rotundus*	anticonvulsion	cyperol cyperen	Bu
	Scirpus fluviatilis	lactagogue		Bu
Epiloboaceae (Oenotheraceae)	*Epilobium pyrricholophum*	common cold antihemorrhagic		Wp
	Oenodera odorata	antipyretic		Rt
	Trapa natans	tonic antipyretic		Fr
Equisetaceae	*Equisetum arvensis*	diuretic	saponin	Ls
	Equisetum hiemale	antihemorrhagic antipyretic diuretic	soluble salicilic acid	Ls
Euphorbiaceae	*Euphorbia spurge*	antihemorrhagic lactagogue		Wp
Eriocaulaceae	*Ericaulon sieboldianum*	headache antihemorrhagic		If
Fabaceae	*Aeschynomene indica*	diuretic		Wp
	Trifolium pratense	expectorant	essential oil coumaric acid	If
	Vicia amoena	analgesic		Ls
	Vicia hirsuta	antihemorrhagic jaundice		Ls
Fumariaceae	*Corydalis ternata*	analgesic	bulbocaprine protopine	Tu
Geraniceae	*Geranium thunbergii*	antidiarrhea	tannin	Ls
Hydrocharidaceae	*Hydrocharis dubia*	antiseptic		Wp
	Ottelia alismoides	antitussive antipyretic		Wp
Juncaceae	*Juncus effusus*	diuretic		Pi

Table 1. continued

Family name	Sci. name	Utilization	Components	Used part
Labiatae	*Ajuga multiflora*	diuretic	iridoid	If
	Elscholtzia ciliata	diuretic	elscholtzia ketone	Ls
	Leonurus sibiricus	stomachic	leonurine	Ls
	Lycopus lucidus	antipyretic	essential oil	Ls
	Mentha arvensis	flavor	menthol menthone	Ls
	Prunella vulgaris	diuretic		If
	Salvia plebeia	antidote	flavonoid saponin	Wp
	Stachys baicalensis	choleretic antiniflammatory	flavonoid agent	Wp
Lemnaceae	*Lemna pausicostata*	sweating antidote		Wp
	Spirodela polyrhiza	sweating antidote		wp
Lobeliaceae	*Lobelia chinensis*	cardiotonic diuretic	lobeline	Wp
Lythraceae	*Lythrum anceps*	antidiarrhea	tannin salicarin	Wp
Malvaceae	*Albutilon avicennae*	antidiarrhea	pentosan	Wp
Marsileaceae	*Marsilea quadifolia*	sweating diuretic antidote		Wp
Oxalidaceae	*Oxalis corniculata*	snake antidote	oxalic acid	Wp
Papaveraceae	*Chelidonium majus*	spasmolytic	chelidonine protopine	Ls
Phyllanthaceae	*Phyllanthus matsumurae*	antidysenteric		Wp
	Phyllanthus urinaria	hepatitis antidysenteric		Wp
Plantaginaceae	*Plantago asiatica*	diuretic antitussive antidiarrhea	aucubin mucilage	Fr
Poaceae	*Imperata cylidrica*	diuretic antihemorrhagic	polysaccharide	Rh
	Miscanthus purpurascens	diuretic	polysaccharide	Rh
Polygalaceae	*Polygala japonica*	expectorant tonic	saponin	Rt
Polygonaceae	*Amblygonon pilosum*	antidiarrhea		Sd
	Polygonum aviculare	anthelmintic	avicularin, emodin	Ls
	Polygonum hydropipe	antihemorrhagic	tadeonol	Ls
	Polygonum cuspidatum	laxative diuretic	emodin stilbene	Rh
	Rumex acetosa	skin disease	chrysophanic acid	Rt
	Rumex crispus	eczema	emodin	RT
	Polygonum perfoliata	snake antidote		Ls
Portulacaceae	*Portulaca oleacea*	diuretic antidote antidysenteric		Wp
Potamogetonaceae	*Potamogeton distinctus*	stomachic		Wp
Pteridaceae	*Pteridium aquuilium*	tonic	starch	Lf

Table 1. continued

Family name	Sci. name	Utilization	Components	Used part
Ranunculaceae	*Clematis apiifolia*	antigout	hederagenin	Rt
	Ranunculus japonlcus	neuralgia	protoanemonine	Rt
Rosaceae	*Duchesnea chrysantha*	inflammatory	polysaccharide	Wp
	Potentilla chinensis	antipyretic antihemorrhagic	tannin	Wp
Rubiaceae	*Galium aparin*	diuretic	flavonoid asperoside	Wp
	Galium verum	choleretic	parustrosid methylvanilin rubiazinprimbelosid	Wp
	Rubia akane	antipyretic	purpurin	Rt
Santalaceae	*Thesium chinense*	diuretic		Wp
Scrophulariaceae	*Veronica didyma*	hernia	aucubin mannitol	Wp
Solanaceae	*Datura stramonium*	anticonvulasion analgesic antitussive	atropine	Lf
	Solanum nigrum	antipyretic diuretic	solanine	Ls

1) Bu : Bulb
Fr : Fruit
If : Inflorescence flower
Lf : Leaf
Ls : Leaf and stem
Pi : Pith
Rh : Rhizome
Rt : Root
Sd : Seed
Tu : Tuber
Wp : Whole plant

Allelopathy in Crop and Pasture Management with Special Reference to Goosefoot *(Chenopodium pumilio)*

A. Cheam,[1] J. Peirce,[1] L. Martin,[2] S. Lee[1] and B. Rayner[1]
[1] Department of Agriculture, Baron-Hay Court, South Perth WA 6151, Australia
[2] Muresk Institute of Agriculture, Northam WA 6401, Australia

Abstract. Evidence of allelopathy as an important factor in crop management is discussed briefly with reference to the weed *Chenopodium pumilio* R. Br. in Western Australia. The overall allelopathic impact was more severe on wheat and lupins (*Lupinus angustifolius* L.) than on legume pastures (*Trifolium subterraneum* L. and *Medicago* spp.). It was demonstrated that shallow seeding of wheat into the goosefoot residues could overcome the allelopathic impact. Wheat was less susceptible than lupins, probably because of its shorter fibrous root system. With lupins, the rapid growth of its tap root is thought to increase the uptake of the rain-soluble allelochemicals being leached down the soil profile. Despite the sensitivity of lupins, early control and incorporation of goosefoot into the soil ensured adequate breakdown of the allelochemicals to allow healthy establishment of lupins at the start of the cropping season.
Key words. Allelopathy, crop management, goosefoot, *Chenopodium pumilio*

Introduction

Along with its importance in natural ecosystems, allelopathy has major implications in agricultural systems (Klein and Miller, 1980). During the 1992 cropping season for example, farmers in Western Australia reported massive crop and pasture failures in fields infested with *Chenopodium pumilio. C. pumilio* is a major summer weed in the Western Australian wheatbelt, and is commonly known as goosefoot. The large quantity of goosefoot residues at the time of seedbed preparation was suspected to be responsible for these failures. To confirm this, wheat, lupins and legume pastures were screened for possible allelopathic injury by goosefoot. Other experiments explored methods to minimise the allelopathic impact.

Materials and Methods

Susceptibility of crop and pasture species

Fresh goosefoot plants were collected from the field. A preliminary extract in distilled water showed that the leaves and stems were richest in the chemical inhibitor. As a result of this test, the extract or leachate required for subsequent experiments was prepared from the leaves and green stems only. The average fresh weight of leaves and green stems cut from eight, 1m x 1m quadrats in a thick patch of goosefoot was first determined. The appropriate quantity of material per 9-cm petri dish was then calculated and the amount was subsequently sandwiched between moist filter papers upon which the test seeds were germinated. Each petri dish was initially treated with 5ml of distilled water followed by the addition of more water, if required.

The species/varieties tested are shown in Figure 1. For each species, 50 seeds were placed in the petri dishes with the following treatments:
(i) distilled water control;
(ii) treatment with goosefoot residue.

Each treatment was replicated four times in a completely randomised design. The dishes were incubated in a germination cabinet set at a 12h photoperiod with alternating temperature regimes of 20/10°C. Germination scores were obtained 2 days later. This short period was sufficient to give complete germination of the control treatments and appeared to be the best for indicating the relative sensitivity of the test species/varieties under study. Measurements of root and shoot lengths were obtained 5 days after incubation.

Minimising allelopathic impact

Two approaches to minimising the allelopathic impact were examined. One takes advantage of the different rooting patterns of wheat and lupins in relation to the high solubility of the allelochemicals. The second approach is to determine the appropriate time of goosefoot control so as to allow sufficient breakdown of the allelochemicals to a level that is non-injurious to crop establishment.

In the first approach, the principle of depth protection was explored. Wheat and lupins were sown 2, 5 and 7 cm in soil into which the goosefoot residues had previously been incorporated in the top 5 cm to represent standard cultivation depth. The incorporated residues were 1 kg fresh wt m^{-2} (harvested from a field density of 50 plants m^{-2}) and 2 kg fresh wt m^{-2}. A treatment without any residue was included as the control. Each treatment combination was replicated three times in a randomised complete block design. Emergence and survival of crop seedlings were recorded 2 and 4 weeks after sowing.

In the second approach, three separate dates of control of goosefoot were compared: February (3 months before crop seeding); March (2 months before crop seeding); and May (at the time of crop seeding). On each date, enough goosefoot plants were uprooted to allow the following treatments:
(i) residues at normal field rate (1 kg fresh wt. m^{-2}), left undisturbed on the soil surface;
(ii) residues at normal field rate, incorporated into the top 5 cm of soil by cultivation;
(iii) residues at twice the normal field rate (2 kg fresh wt. m^{-2}), left undisturbed;
(iv) residues at twice the normal field rate, incorporated into the top 5 cm of soil by cultivation;
(v) no goosefoot control, soil undisturbed;
(vi) no goosefoot control, soil cultivated.

Each treatment was replicated three times in a randomised complete block design.

In May, when the soil was moist enough, lupins, wheat and pasture species (50 seeds each) were sown into each of the six treatments. Four weeks later, the number of healthy seedlings was recorded. The lupin response is of special interest because of its sensitivity, hence only the lupin results in this experiment are reported here. The results were expressed as a percentage of the respective control.

Statistical analyses
Data were analysed by analysis of variance, excluding the nil plant treatments of Table 1. No transformations of the data were required.

Results and Discussion

Crop and pasture susceptibility
Overall , wheat and lupins appeared to be more sensitive to goosefoot residues than legume pasture species (Figure 1).

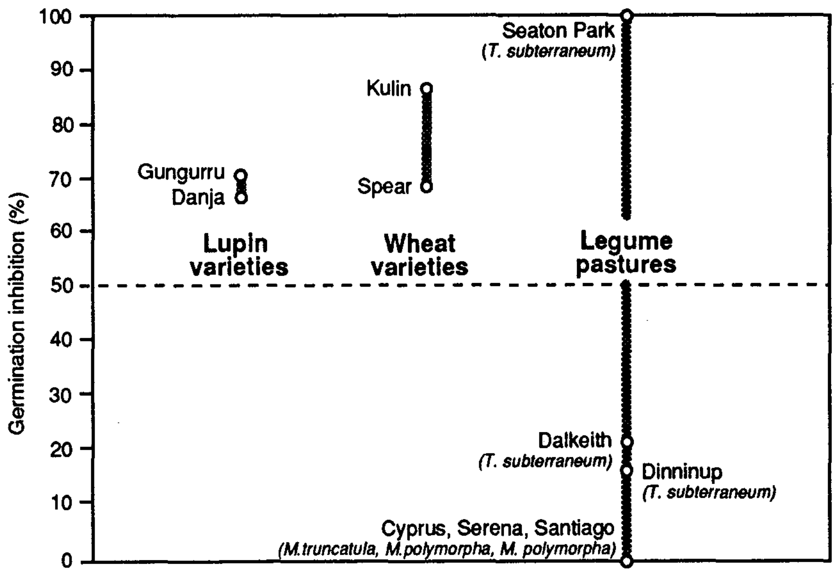


Figure 1. Susceptibility ranges of crops and pastures in response to leachates of goosefoot

Washing the affected seeds and seedlings in running tap water to simulate rainfall, did not result in the resumption of normal germination and growth in the affected species.

Germination inhibition ranged from 0 to 100 per cent in the pasture species, with Seaton Park subterranean clover (*T. subterraneum* L.) being the most sensitive (Figure 1). Santiago burr medic (*M. polymorpha* L.) was the least sensitive. Germination inhibition ranged from 0 to 21% of the other clovers and medics. As a group, the clovers appeared to be more susceptible than the medics. There was inhibition of seedling growth in all cases; growth suppression ranged 70 - 90%.

Miminising allelopathic impact

It was demonstrated that shallow seeding of wheat into the goosefoot residues, even at twice the field level, could overcome the allelopathic impact (Figure 2).

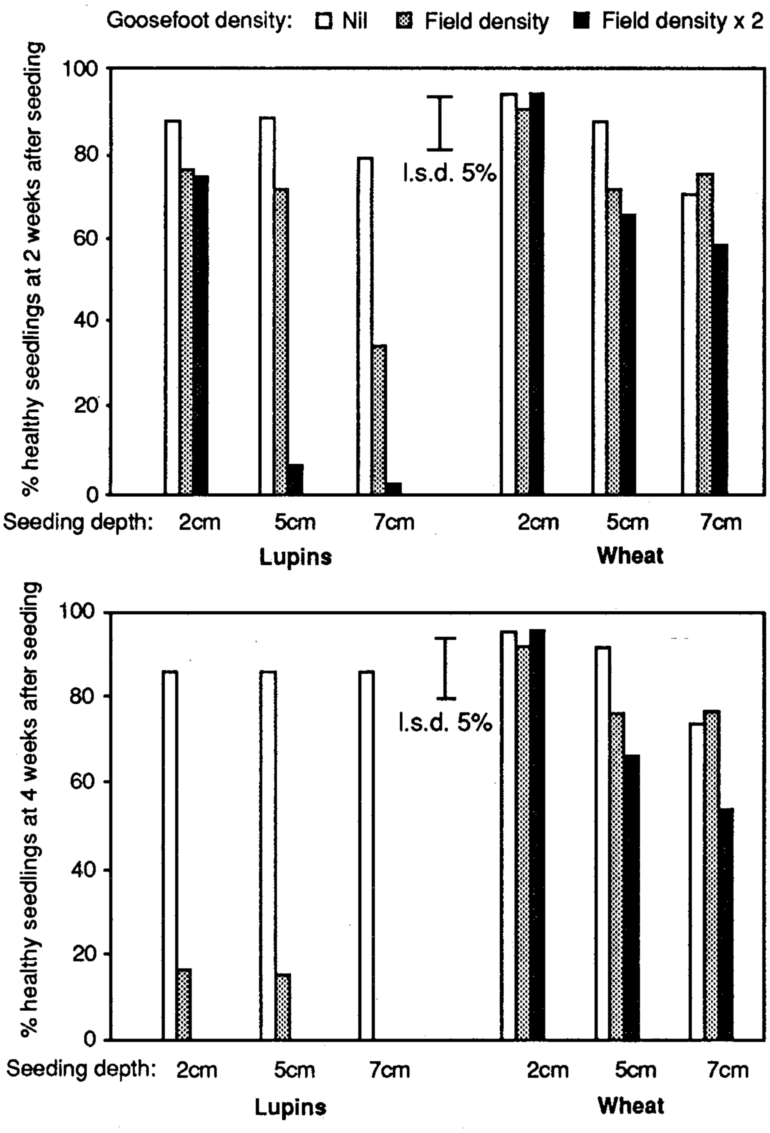


Figure 2. Responses of lupins and wheat at 2 and 4 weeks after seeding at various depths into goosefoot residues that were incorporated into the top 5 cm of the soil

Wheat was less susceptible than lupins, perhaps because of its shorter fibrous root system. With lupins, the rapid growth of its tap root may have increased the uptake of the rain-soluble allelochemicals that were being leached down the soil profile. The movement of the allelochemicals down the soil profile was noted in a separate test using white mustard (*Sinapis alba* L.) as a bioassay species.

In both lupins and wheat, the amount of allelopathic injury increased with the depth of seeding. This could be attributed to the fact that deeper planting has the effect of increasing the length of the shoot/hypocotyl below the ground, thus providing a greater target area for the allelochemicals.

Despite the sensitivity of lupins, it was shown that early control of goosefoot (at least 2 months prior to sowing), followed by its incorporation into the soil, ensured breakdown of the allelochemicals to allow good establishment of lupins (Table 1).

Table 1. Emergence of lupins (as percentage of control), four weeks after sowing

Treatment	Time of kill of goosefoot		
	February	March	May
1. Nil plant, uncultivated	100	100	100
2. Nil plant, cultivated	100	100	
3. Field density[A], uncultivated	84.4	85.1	70.3
4. Field density, cultivated	112.7	107.4	
5. High density[B], uncultivated	56.4	76.6	58.1
6. High density, cultivated	105.1	104.4	
l.s.d. (p = 0.05)			
To compare treatments 3 - 6 with 1 or 2	27.3	17.9	20.5
To compare treaments 3 - 6	38.6	25.3	29.0

A. Field density (50 plants m^{-2}) = 1 kg fresh wt m^{-2}
B. High density = 2 kg fresh wt m^{-2}

Incorporation of even the high density residues significantly overcame the phytotoxicity. In contrast, emergence of lupins seeded into high density surface residues was reduced by 24 to 44%.

The more rapid breakdown of the allelochemicals in the soil-incorporated residues compared to the surface residues, may have been due to microorganisms which play an important but often ill-defined role (Lovett, 1987).

Control and incorporation of goosefoot at the time of crop seeding in May did not allow sufficient time for the breakdown of the allelochemicals. About 30 and 42% of the lupin seedlings were killed when seeded into goosefoot residues at field and high density, respectively.

The evidence presented here suggests that lupins should not be planted in a goosefoot-infested farm unless adequate measures, such as early kill of the goosefoot followed by cultivation to incorporate the residues, have been taken to ensure the breakdown of the residues. It is also evident that the allelopathic effects of fresh goosefoot residues can be avoided by sowing wheat at a shallow depth (2 - 3 cm). Finally, caution is needed when resowing legume pastures in goosefoot residues. The less sensitive medics are preferred to the subterranean clovers, and Seaton Park subterranean clover should be avoided because of its high susceptibility.

Acknowledgments. We wish to thank R. Cousens and J. Dodd for their helpful comments on this paper. The assistance of R. Madin, J. Buckley, E. Gajda and L. Lawrence is gratefully acknowledged. The co-operation of P. Gillete in providing permission to undertake field experiments on his farm is greatly appreciated. Mrs E. J. Speijers provided advice on statistical analysis.

References

Klein, R.R. and D.A. Miller. 1980. Allelopathy and its role in agriculture. *Communication in Soil Science and Plant Analysis* 11 (1), 43 - 56.

Lovett, J.V. 1987. *Allelopathy in Australia: Bacterial mediation. In* 'Allelochemicals: Role in Agriculture and Forestry', ed. G.R. Waller. American Chemical Society, Washington, DC.

Screening of Allelopathic Cover Crops and their Application to Abandoned Fields

Y.Fujii * , H.Inoue, S.Ono, K.Sato, B.A.Kahn *[1] and G.R.Waller *[1]

Shikoku National Agricultural Experiment Station, Zentsuji,Kagawa 765,Japan

*[1]Oklahoma State University, Stillwater,OK 74078,USA

Abstract. Allelopathic cover crops are the most promising application of allelopathy to weed control in abandoned fields, now increasing to 5 to 10% of the cultivated fields in Japan. To access the allelopathic activity, new specific bioassay procedures called "plant box method" and "sandwich method" were developed, and over 300 plant species have been evaluated. Hairy vetch(Vicia villosa) was the most promising cover crop. There are many factors involved in weed control by cover crops, among which are competition for light and nutrients, in addition to allelopathy. A "weed suppression equation" including these factors was proposed, and leguminous cover crops such as hairy vetch, velvetbean, and gramineous cover crops, oats, rye and barley were found the most promising. We will also discuss practical methods of using allelopathic cover crops to control weeds in abandoned fields.

Key words. allelopathy, cover crop, hairy vetch, weed suppression equation

Introduction

Abandoned paddy fields are increasing because of the aging of farmers and industrialization in Japan. Now it reaches nearly 10%, including fallow fields coordinating the production of rice. These fields tend to grow much weeds and in serious case, weed-trees are covering the surface. In such case, it is difficult or take much money to recover to their original paddy fields.

Our group has been engaged in a search for allelopathic plants in order to determine allelopathy and its mechanism. In the course of these study, we developed some new methods to discriminate and identify allelopathy from other competitive factors such as nutrients, light and water(Fujii, 1994). We have reported allelopathy in velvetbean(Fujii, 1994), hairy vetch(Fujii et al. 1992, 1995), medicinal plants(Fujii et al.1991), and others.

In this research, we have developed a new system which can show the possibility of allelopathy, named "plant box method", and "sandwich method".

These method involves mixed planting using agar medium, and exudation of allelochemicals from leaves and/or roots. These methods can show the allelopathic action of root exudates and leaf leach.

Some farmers suggested from their experiences that some ground cover plants suppress weeds drastically. There is a possibility that some cover crops could be used for practical weed suppression. Then we began to screen the allelopathic activity of cover plants by plant box method and sandwich method. Hairy vetch was proven to be most practical. Then we began the application to abandoned fields and orchards.

Materials and Methods

The "plant box method" was developed(Fujii, 1991), and more than 300 species were tested. Young plants were cultivated for one to two month in a sand, in standing water containing a nutrient solution. The receiver plant used for bioassay was lettuce(Great Lakes 366), because it is highly sensitive to bioactive substances.

Plant growth inhibitory activities of cover crops were tested by water and methanol extraction. Dried leaves and shoots(60 ℃,over night,forced air dry) were extracted by 150 times of water and 40times of methanol.

Field test for weed suppression were designed: 1)within the experimental station, 1mx1m quadrat were seeded by candidate cover crops, according to statistical design, more than 4 times replication. 2)at the fields of cooperative farmers, 0.1 to 0.5 ha fields were seeded mainly hairy vetch, the most promising cover crop. Paddy fields and ornamental crops, japanese persimmon, pear garden, and japanese mandarin orange fields were used.

Results and Discussion

The results of screening of candidates for allelopathic cover crops from leguminous and gramineous species by Plant Box Methodwere shown in Table 1.In this table, radicle % means the percentage of the root radicle by length of the young lettuce plants present in the root zone of each donor plants, based on the calculation of radicle length within the root zone controlled by donor plants. The results show leguminous cover crops such as Mucuna pruriens, Hairy vetch, Yellow Sweet Clover and White Sweet Clover have strong allelopathic inhibitory activities. Gramineous species, such as oat, wheat, millet, rye shows strong inhibitory activity.

Table 2 shows the inhibitory activities of water and methanol extracts of cover crops. Velvetbean and hairy vetch showed the strongest inhibitory activity in both water and methanol extract.

Then we planted the allelopathic candidates to the fields. Table 3 shows the result. Without weeding, hairy vetch, oat, barley, rye, wheat showed strong inhibitory activity of weeds, but chinese milk vetch, which is a traditional green manure in Japan and China, showed little weed suppression.

After these preliminary experiments, we decided to use hairy vetch in order to suppress weeds in abandoned fields. Table 4 shows that hairy vetch suppress weeds practically than chinese milk vetch. Oats also inhibited the growth of weeds, but we must cut down the stems. On the other hand, hairy vetch will die automatically to be a straw-like coverage. Then we concluded hairy vetch the most promising cover crop for the protection of weeds(Fujii et al,1994).

Table 5 shows the application of "Weed Suppression Equation" to the field experiments(Fujii, 1995). In the table, next equation; $F=A \times R \times C \times \alpha$ was postulated. In this equation,"A" means the allelopathic factor, whose upper limit is 5, "R" means the growth rate of plant and representative of competition for nutrients and water, "C" means the covering factor and representative of competition for light. We compared the contribution of "A", and found it is far better easy to simulate the "W", the real weed suppression rate on the fields.

Acknowledgement: We sincerely thank to Mr.Satoru Oohiro and Mr.Takakazu Hirata for their technical assistance on the field experiments.

References :

Fujii Y. and T.Shibuya. 1991. A new bioassay for allelopathy with agar medium I. Assesment of allelopathy from litter leacheate by sandwich method. Weed Res., Japan 36(Suppl) 150-151.

Fujii Y.,T.Shibuya, and T.Yasuda. 1991. Survey of Japanese medicinal plants for the detection of allelopathic properties. Weed Res., Japan 36, 36-42.

Fujii Y. and T.Shibuya. 1992. Allelopathy of hairy vetch(Vicia villosa). Assessment of allelopathic activity and weed control in the field. Weed Res.,Japan 37(Suppl) 160-161.

Fujii Y. 1994. Screening of allelopathic candidates by new specific discrimination and assesment methods for allelopathy, and the identification of L-DOPA as the allelopathic substance from the most promising velvetbean. The Bulletin of the National Institute of Agro-Environmental Sciences, 10, 115-218.

Fujii Y. S.Ono. and K.Sato. 1994. Weed suppression by winter cover crops such as hairy vetch, oats, rye, barley and wheat, and its relation to Plant Box Test. Weed Res., Japan 39(Suppl) 258-259.

Fujii Y. 1995. Weed suppression equation including allelopathy and other competitions and its application to the weed control in the field. Weed Res., Japan 40(Suppl) 212-213.

Table 1 Assessment of allelopathic activity by Plant Box method

Scientific name(common name)	Radicle[%]		n	Root D.W.[mg]
----(Leguminosae)				
★ *Mucuna pruriens* var. *utilis* (av. of 6 cv.)	13.4	★★	22	217
★ *Vicia faba*(Broad Bean) (av. of 10 cv.)	19.4	★	10	258
★ *Vicia villosa* (Hairy Vetch)(av. of 4 cv.)	20.3	★	21	148
★ *Melilotus officinalis* (Yellow Sweet Clover)	23.4	★	2	440
★ *Vicia sativa*(Common Vetch)	25.4	★	5	189
★ *Canavalia ensiformis*(Jack Bean)	28.1	★	11	251
★ *Pueraria lobata* (Kudzu)	28.4	★	4	215
★ *Pueraria phaseoloides* (Tropical Kudzu)	28.5	★	2	142
☆ *Medicago sativa* (Alfalfa)	31.7	☆	11	372
☆ *Trifolium incarnatum*(Crimson Clover)	36.4	☆	4	250
☆ *Tephrosia candida* (White Tephrosia)	36.9	☆	3	301
☆ *Cajanus cajan* (Pigeon Pea)	39.7	☆	10	192
☆ *Latyrus sativus* (Grass Pea)	40.8	☆	7	169
☆ *Cicer arietinum* (Chickpea)	43.9	☆	6	138
Vigna radiata (Mung Bean)	47.1		6	329
Trifolium pratense(Red Clover)	52.7		6	114
Crotaralia juncea (Sunn Hemp)	56.9		4	198
Astragalus sinicus(Chinese Milk Vetch)	58.6		7	213
Lupinus albus (White Lupine)(av.of 5 cv.)	59.9		10	140
Trifolium subterraneum(Subterranean Clover)	70.4		6	251
Trifolium repens(White Clover)	71.7		5	206
Glycine max (Soybean)(av.of 2 cv.)	76.3		8	119
---- (Gramineae)				
★ *Avena sterilis*(Wild Oat)	12.0	★★	5	339
★ *Triticum polonicum*(Polish Wheat)	13.3	★★	3	422
★ *Panicum miliaceum* (Millet,Shikoku local cv.)	14.4	★★	7	378
★ *Setaria italica* (Foxtail Millet)	18.0	★	5	251
★ *Avena wiestii* (Wild Oat)	24.1	★	2	187
★ *Triticum aestivum* (Mulch Wheat)	28.0	★	2	290
★ *Anthoxanthum odoratum* (Sweet Vernalgrass)	28.8	★	5	238
★ *Secale cereale*(Rye)(av. of 5 cv)	29.0	★	12	394
★ *Avena sativa* (Oat) (av. of 12 cv)	29.5	★	21	237
☆ *Setaria italica* (Italian Millet)	30.2	☆	2	223
☆ *Festuca rubra* (Chewing Fescue)	30.3	☆	3	264
☆ *Avena fatua* (Karasumugi)	33.0	☆	2	206
☆ *Sorghum bicolor* (Sorghum)	35.5	☆	9	263
☆ *Hordeum vulgare* (Barley)(av. of 7 cv)	37.9	☆	11	307
☆ *Panicum maximum* (Guinea Grass)	39.7	☆	4	356
☆ *Triticum dicoccum* (Emmer Wheat)	40.5	☆	3	297
☆ *Panicum antidotale*(Blue Panicgrass)	43.5	☆	3	312
☆ *Festuca arundinacea* (Tall Fescue)	45.0	☆	8	445
Sorghum sudanense (Sorghum sudanense)	45.2		6	343
Echinochloa crus-galli (Inubie)	48.0		3	301
Digitaria sanguinalis var. *ciliaris*	49.2		6	232
Poa pratensis (Kentucky Bluegrass)	59.5		12	165
Zea mays(Corn)(av. of 3 cultiver)	60.0		7	158
Dactylis glomerata(Orchard Grass)	61.9		5	173
Echinochloa utilis(Hie)(av. of 3 cv)	62.3		10	354
Lolium perenne(Perennial Ryegrass)	63.6		7	337
Paspalum dilatatum(Dallis Grass)	72.4		5	464
Lolium multiflorum(Italian Ryegrass)	73.9		11	340
Phalaris arundinacea(Reed Canary grass)	76.3		4	254

☆ 30-45%、 ★ 15-30% 、 ★★ 0-15%

Table 2 Effect of water and methanol extracts of cover crops

Cover Crop	Water extract(X150)			Methanol extract(X40) [*1]		
	Germi-nation	Radi-cle	Hypo-cotyl	Germi-nation	Radi-cle	Hypo-cotyl
Cajanus cajan	97	41	76	83	13 [*2]	15
Centrosema pubescens	100	53	118	100	37	80
Crotaralia juncea	100	55	120	97	51	105
Leucaena leucosephala	100	29	119	100	67	102
Mucuna pruriens	100	17	102	87	26	61
Tephrosia candida	100	58	106	100	41	95
Vicia villosa	100	12	89	90	18	52

*1 Concentration of each cover crops(leaves) are; water extract: 6.7 mg-d.w./ml, methanol extract: 25 mg-d.w./1ml
*2 Underlined show strong inhibition(<66% inhibition).
*3 from Fujii and Shibuya(1992)

Table 3 Effect of cover crops on weed control in upland field

Cover Crop	W[1)]		Dry weight[3)]
Control(No-weeding)	0	a[2)]	----
Astragalus sinicus(Chinese Milk Vetch)	36	b	167
Lupinus albus (Lupin)	49	b	341
Medicago sativa (Alfalfa)	77	cd	384
Melilotus albus (White Sweet Clover)	−16	a	30
Trifolium repens (White Clover)	78	cd	356
Vicia villosa (Hairy Vetch)	90	cd	816
Avena sativa (Oat)	99	cd	994
Hordeum vulgare (Barley)	99	cd	1173
Secale cereale (Rye)	99	d	693
Triticum aestivum (Wheat)	99	d	1751
Brassica campestris (Field Mustard)	97	cd	834
Herbicide (Satanbaaro 40 kg ha^{-1})	91	cd	---
Rice straw mulch (1000 kg ha^{-1})	87	cd	(1000)

1) Weed control %. Control weed dry wt=3810 kg ha^{-1}.
2) The same letter means not significantly different by DMT(a=0.01).
3) Dominant weeds are, *Capsella bursa-pastoris* and *Lamium amplexicaule*.
4) Seeding date:1992.1105, Sampling date:1993.0420.1
5) Four replications, each plot is 4 m^2. 6) From Fujii et al.(1994)

Table 4 Effect of cover crops on weed control in abandoned paddy field

Cover crop	W[1)]		Crop dry yield[3)]
First Sampling(1993.0507)	(%)		[kg ha^{-1}]
Control(No-weeding)	0	a[2)]	----
Astragalus sinicus (Chinese Milk Vetch)	82	b	4310
Vicia villosa (Hairly Vetch)	99	b	5840
A. sativa+*V.v* (Oat and Vetch)	99	b	7300
Second Sampling(1993.0610)			
Control(No-weeding)	0	a[2)]	----
Astragalus sinicus (Chinese Milk Vetch)	59	b	1347
Vicia villosa (Hairy Vetch)	100	c	1465
A. sativa+*V.v* (Oat and Vetch)	100	c	1371

1) Weed control %. Control weed dry wt=2810(1st), 1546(2nd) kg ha^{-1}.
2) The same letter means not significantly different by DMT(a=0.05).
3) Dominant weeds are, *Alopecurus aequalis* and *Lamium amplexicaule*.
4) Seeding date:1992.1028, Sampling date:1993.0507(1st),0610(2nd).
5) Four replications, each plot is 500 m^2. 6) From Fujii et al(1994)

Table 5 Application of Weed Suppression Equation to the Field Experiments

Scientific name(common name)	A	R	C	F	W*1
(Spring seeded cover crops)					
(Leguminosae)				(%)	(%)
Cajanus cajan (Pigeon Pea)	2	2	5	2	0
Calopogonium mucunoides (Calopogonio)	3	8	20	48	50
Canavalia ensiformis(Jack bean)	4	2	6	5	2
Cassia tora (Sickle Senna)	3	5	10	15	39
Crotaralia juncea (Sunn Hemp)	2	4	10	8	2
Glycine max (Soybean)	1	5	10	5	8
Mucuna pruriens var.*utilis*(Velvet bean)	5	8	15	60	50
Vicia villosa (Hairy Vetch)	4	8	10	32	47
Vigna angularis (Adzuki bean)	3	7	15	32	41
Vigna radiata (Mung bean)	2	5	5	5	2
(Gramineae)					
Panicum maximum (Guinea Grass)	3	10	20	60	83
Panicum miliaceum (Millet)	4	5	15	30	44
Setaria italica (Foxtail Millet)	5	5	10	25	16
(Other family)					
Amaranthus tricolor (Ganges Amaranth)	2	10	15	30	21
Celosia argentea(Feather Cockscomb)	3	10	20	60	85
Chenopodium album (Goosefoot)	3	10	20	60	85
Corchorus olitorius (Nalta Jute)	3	8	18	43	46
Gossypium barbadense(Cotton)	2	8	15	24	35
Helianthus annuus (Sunflower)	3	10	20	60	85
Ricinus communis(Castor bean)	2	8	10	16	14
(Autumn seeded cover crops)					
(Leguminosae)					
Astragalus sinicus(Chinese Milk Vetch)	2	9	20	36	36
Latyrus sativus (Grass Pea)	3	10	20	60	85
Lupinus albus (White Lupine)	3	8	15	36	49
Pisum sativum (Pea)	5	8	10	40	90
Trifolium pratense(Red Clover)	2	10	20	40	78
Vicia villosa (Hairy Vetch)	5	10	20	100	98
(Gramineae)					
Avena sativa (Oat)	5	10	20	100	99
Hordeum vulgare (Barley)	5	10	20	100	99
Lolium perenne(Perennial Ryegrass)	2	8	20	32	64
Phleum pratense (Timothy)	2	8	20	32	69
Secale cereale(Rye)	5	10	20	100	99
Triticum sp. x *Secale* sp. (Triticale)	4	10	20	80	98
Triticum aestivum (Common Wheat)	3	8	20	48	95
(Other family)					
Brassica alba (White Mustard)	4	8	20	64	95
Brassica napus (Rape)	4	10	20	80	97
Allium cepa (Onion)	2	3	5	3	0
Allium fistulosum (Welsh Onion)	1	2	5	1	0

*1 Weed suppressin % on the fields, 100% means complete suppression.
*2 Underlined species are promising from F-factor.

Allelopathic Substances Contained in Gooseweed (*Sphenoclea zeylanica* Gaertn.)

C. Premasthira* and S. Zungsonthiporn.

Weed Science Group, Botany and Weed Science Division
Department of Agriculture, Chatuchak, Bangkok 10900, Thailand.

Abstract: The allelopathic effect of methanol extracted substances from gooseweed was examined by rice seedling bioassay. The results showed that the effectiveness of substances in gooseweed increased with age and the extracted substances from each part of gooseweed caused different effects on rice seedling growth. The phytotoxicity of extracted substances from various parts of gooseweed were ranked as follows: inflorescences (seed),leaves, stem and root.

" ***Key words*** " Allelopathic Substances, Plant part, *Oryza sativa* cv. RD23, Phytotoxicity, Growth stage.

Introduction.

Gooseweed (*Sphenoclea zeylanica* Gaertn.) is a common weed in Thailand. Especially in the paddy fields , gooseweed is the dominant community , meaning that gooseweed has higher competitive ability as compared with rice plants and other weeds. This phenomenon occurs because of the characteristic of the plant which contains plant growth inhibiting substances. Preliminary research found that methanolic extract from gooseweed inhibited rice seedling growth (Premasthira , 1985). The plant growth inhibiting substances in plants retains in every part of plant (Rice, 1974). Their efficacy are different and based on types of part (Ashraf, 1980 ; Rao, 1977) and age of plant (Kanchan, 1979). Therefore, this study is conducted to determine the stage of gooseweed exerting maximum inhibiting effects on rice plant growth, and determine the different levels of phytotoxicity from various parts.

Materials and Methods

Three leaf stage of gooseweed seedlings were grown in 30 cm diameter pot. The gooseweed plant at 15 ,30 ,45 ,60 ,75 and 90 days old were collected for phytotoxic investigation by rice seedlings bioassay. The whole plant and the part of root, stem, leaves and inflorescences of 15 , 30 , 45 , 60 , 75 and 90 days old gooseweed were collected and kept in freezer as materials. These materials were extracted with cold methanol solvent. One hundred grams of each material was homogenized with five times (w/w) of cold matanol twice by universal homogenizer. (Nippon seiki , type HC) Filtered methanol extracts of 1 , 2.5 and 5.0 gram equivalent to fresh material were taken and poured into glass vial (30 mmD x 120 mmH) containing 1.5 gram of cellulose powder (Toyo , type D.) After drying in vaccuo , 4 ml of distilled water was added to each vial. Six uniformly germinated rice seeds (*Oryza sativa* cv.RD 23.) were placed in the vial. The vials were covered with vinyl film and placed in a growth chamber with a temperature of 30 C and a light intensity of 3,500 lux at plant level. The length of root and second leaf sheath were measured at seven days after treated. Each treatment was replicated four times.

Results and Discussions

The effects of extracted substances from different stage of whole plant and each part of gooseweed plant on rice seedling growth were examined. The results are in Table 1, 2 and 3. The effects of extracted substances from whole plant gooseweed at different stages showed in Table 1. It revealed that the root length of rice seedlings was most inhibited when treated with 1.0 gram fresh weight of extracted substances from 60 and 75 day old gooseweed followed by 90 , 45 , 30 and 15 days old gooseweed, respectively; and root length was more inhibited than 2nd leaf sheath length of rice seedlings. The rice seedlings growth was more affected when having the higher concentration of extracted substances. These results indicated that the effectiveness of extracted substances was related to the growth stage of gooseweed. According to the observation, it was found that the morphology of each growth stage and the development of each part of gooseweed were different. The 15 day old gooseweed had young leaves and stem. The leaves and stem of 30 and 45 day old gooseweed developed more completely than 15 day old gooseweed. The inflorescences of gooseweed were formed 45 days after planting. The 60 , 75 and 90 day old gooseweed were at the stages of having completed their growth, so that their parts were also fully developed at these stages.Most of the inflorescences were completely mature at 60 days, and about 1/3 and 1/2 of inflorescense developed into seeds in 75 and 90 days, respectively. From this results, it appeared that the effectiveness of extracted substances on rice seedling growth was based on the growth stage of gooseweed. Besides, the part at each stage of gooseweed was differently developed. Therefore, the inhibition of extracted substances from each part at the various stages of gooseweed was investigated.

The results in Table 2 show that the root length of rice seedlings was inhibited by the extracted substances from the root of 30 day old gooseweed followed by 45, 60, 75 and 90 day old gooseweed, respectively. The extracted substances from gooseweed stem was most effective at 75 day old gooseweed, followed by 90, 60, 45 and 30 day old gooseweed. The inhibition of extracted substances from leaves of 75 day old gooseweed was more effective than 60, 90, 45 and 30 day old, respectively. The of 90 day old gooseweed had more inhibitory effect on rice seedling growth than 75 and 60 day old. The results appeared that the effectiveness of extracted substances in root of gooseweed decreased when the age increased. Yet, the inhibition of extracted substances from stem and leaves increased while the age increased. The most effective substances were derived from gooseweed stem and leaves at 60-90 days. The inflorescences of 90 day old had more effective substances than the 75 and 60 day old gooseweed, respectively. Because the flowers of 90 day old gooseweed developed into more seeds than the 75 and 60 day old gooseweed, meaning that the gooseweed seeds had the most inhibiting substances.

At the mature stage of goooseweed which were 60, 75 and 90 day old, the effects of extracted substances from root, stem, leaves and inflorescences on rice seedling growth were examined at the same stage. The results showed that the root length of rice seedlings treated by the extracted substances from inflorescences was shorter than from leaves, stem and root, respectively in every growth stage. (Table. 3). It appeared that at the same growth stage of gooseweed, the extracted substances from each part had different inhibition on root and 2nd leaf sheath of rice seedlings. The extracted substances from inflorescences had the most inhibitory effect on of rice seedling growth. Moreover, the effectiveness of extracted substances from inflorescences and leaves were not significantly different, but the extracted substances from inflorescences and leaves were more significantly effective than stem and root of gooseweed, respectively. Yet, the effectiveness of extracted substances from leaves and stem of gooseweed at 90 days were not significantly different. According to Rice (1974), the most allelopathic substances in plants are the secondary chemical compound that occur during biosynthetic pathway in the plant part. They are sporadic occurrence in every part and those chemical substances were related to the metabolism of any part. Thus, the effects of substances in various parts are different.

It can be concluded that gooseweed which is a common weed in paddy fields contains the strongest plant growth inhibiting substances on rice seedlings. The effectiveness of plant growth inhibiting substances in gooseweed was based on the age of plant. The mature stage of gooseweed which had complete parts had the most inhibitory substances. In addition, the phytotoxicity retained in these parts were different. They were ranked as inflorescences (seed), leaves, stem and root, respectively.

References

Ashraf, N. and Sen, D.N. 1980. Allelopathic potential of *Celosia argentea* in arid land crop fields. Weed Abst. vol. 29:4158.

Kanchan, S. D.and Jayachandra. 1979. Allelopathic effects of *Parthenium hysterophorus* L. 1. Exudation of inhibitors through roots. Plant and Soil.vol. 53:27-35.

Premasthira, C. ; S. Zungsonthiporn. and J. Harada. 1985. Plant growth inhibiting effects of weed species with reference to allelopathy. The Tenth Conference of The Asian-Pacific Weed Science Society. Proceeding 2 p 548-562.

Rao, A.N.; Dagar, J. C.and Dubey, P. S. 1977. Phytoallelopathic potential of *Parthenium hysterophorus* L. Indian Journal of Weed Science. vol. 9:24-30.

Rice, E. L. 1974. The Allelopathy. Academic Press New York. 353 p.237-244.

Table 1: Effects of extracted substances from different stages of whole plant gooseweed (*Sphenoclea zeylanica* Gaertn.) on rice seedling growth.

Day after planting	Concentration of substances					
	Root length (% of control)			2^{nd} leaf sheath length (% of control)		
	1.0	2.5	5.0	1.0	2.5	5.0
15	104.90 a	66.22 a	26.82 a	69.37 a	55.38 a	63.79 a
30	44.40 b	9.57 b	0.33 b	19.69 c	52.30 a	22.36 c
45	43.19 b	7.15 b	0.10 b	54.42 ab	36.83 ab	27.10 c
60	7.03 d	0.77 b	0.00 b	39.17 b	23.30 b	0.98 d
75	7.88 d	0.17 b	0.00 b	65.44 a	19.57 b	0.00 d
90	24.06 c	10.47 b	3.97 b	66.89 a	47.76 a	39.37 b

Values within a column followed by the same letters are not significantly different at 5 % by DMRT

Table 2: Comparison of phytotoxicity from different parts at each stage of gooseweed (*Sphenoclea zeylanica* Gaertn.) on root (R) and 2^{nd} leaf sheath (S) length of rice seedlings.

Day after planting	Part of gooseweed plant							
	Root		Stem		Leaves		Inflorescences	
	R	S	R	S	R	S	R	S
30	28.54 c	42.87ab	81.24 a	36.41 c	79.80 a	46.15 a	-	-
45	51.14 b	44.59ab	36.40 b	59.89 b	15.26 b	34.31 a	-	-
60	54.37 b	28.02 b	27.48bc	41.59 c	4.19cd	44.14 a	3.72 a	30.38 a
75	77.13 a	51.13ab	10.76 d	74.05 a	1.55 d	38.14 a	1.06 b	40.71 a
90	69.08 a	68.45 a	17.67cd	62.30 b	8.00 c	41.49 a	0.40 b	42.39 a

Values within a column followed by the same letters are not significantly different at 5 % by DMRT

Table3: Comparison of root (R) and 2^{nd} leaf sheath (S) length of rice seedling as affected by 1.0 gram fresh weight from each part of gooseweed (*Sphenoclea zeylanica* Gaertn.) at the same growth stages.

Part of gooseweed plant	Day after planting (days)					
	60		75		90	
	R	S	R	S	R	S
Root	54.37 a	28.02 b	77.13 a	51.13 ab	69.08 a	68.45 a
Stem	27.48 b	41.59 a	10.76 b	74.05 a	17.67 b	62.30 a
Leaves	4.19 c	44.14 a	1.55 c	38.14 b	8.00 b	41.49 a
Inflorescences	3.72 c	30.38 b	1.06 c	40.71 b	0.40 c	42.39 a

Values within a column followed by the same letters are not significantly different at 5 % by DMRT

Approaches in Rice Allelopathy Research

Maria Olofsdotter* and Domingo Navarez
International Rice Research Institute, P.O. Box 933, 1099 Manila, Philippines

Abstract. The development of an allelopathic rice cultivars, able to selectively control weeds requires a concerted research effort focused on discovery and validation of allelopathic potential. We also need to consider possible approaches, in terms of weed control, to reach the goal. One of the best approaches is to utilize the knowledge about critical periods in weed-crop interaction. Plant interference in the early growth stages determines the negative effects from weeds at the end of the season. Therefore, allelopathy research must be directed towards effects in the early growth stages, more precisely the first month of growth. What we want to find is germination inhibition, germination delay, early growth inhibition or retardation. Allelochemicals are supposed to have synergistic effects. Therefore, bioassays with single allelochemicals alone will not provide sufficient information. Dilution assays as used in herbicide and pharmacology studies, with mixtures of allelochemicals make it possible to find the most efficient mixture of chemical compounds in terms of biological activity. By using these techniques, it is possible to determine the most efficient concentration combination of several different allelochemicals. Using the results from these assays should make it possible to proceed with efficient screening of rice germplasm using HPLC or other modern tools.
Keywords. Allelopathy, rice, *Oryza sativa*, methodology, bioassay

Introduction

Weeds are a major problem throughout the rice producing world. Weed problems are traditionally solved to the degree labor for handweeding is available. Access to herbicides is today helping in decreasing the weed problems. However, increasing farm labor costs and environmental concerns about pesticide use, make it increasingly important to investigate alternative and sustainable weed control methods. One possible sustainable method is utilization of allelopathic potential in plants.

Allelopathic potential can be utilized for weed control in four ways: 1. plant associated allelopathic plants to provide weed control, 2. use allelopathic plants in the crop rotation and obtain allelopathic activity from plant residues in soil, 3. identify and isolate potent allelochemicals and use these as herbicides and, 4. optimize the allelopathic potential in the crop by developing allelopathic cultivars (Gliessman, 1982; Duke, 1985). All of these methods have some constraints that need to be considered.

Intercropping with an allelopathic companion crop to control weeds is beneficial only if the intercropped system is as profitable as the major crop in monoculture. Intercropping in intensive cropping systems also presents technical problems, such as harvest etc. There are also possible positive effects of an intercropping system, such as increased soil organic matter and use of a nitrogen fixing intercrop.

Allelopathic plant residues in the soil is an ideal way of utilizing allelopathy but there are problems in forecasting the allelopathic potential in the soil. Many allelochemicals are easily degraded and small variations in climate or oxygen supply can result in large variation in allelochemicals available in the soil. High concentrations of allelochemicals could raise ecotoxicological concerns in terms of accumulation of phytotoxins in the soil and their impact of the soil microflora or in terms of autointoxi- fication (Chou, 1987).

Allelochemicals used as herbicides present another problem. Access to them could be as poor as access to herbicides in countries with poor infrastructure and limited resources. Another problem is that the allelochemicals, even though produced by plants, may have as much ecotoxicological impact as synthetic pesticides, and therefor should undergo the same strict release procedure as pesticides.

Development of allelopathic crop cultivars is probably the best solution for many parts of the world, both in terms of environmental safety and accessibility, but it is also the solution that requires much research on both genetic control of allelopathic potential and in allelochemicals.

Allelopathic activity in a wide range of plant species has been reported. However, a problem in allelopathy research has been the lack of consistent bioassay techniques to distinguish allelopathy from other plant interference components. Protocols for allelopathy research have been published but work in areas such as methods and proper statistical procedures is still needed. Fuerst and Putnam (1983) published a protocol that we feel deserves attention. Their protocol:

1. Demonstrate allelopathy using suitable control procedures.
2. Isolate and characterize allelochemicals and assay the isolates on sensitive plants.
3. Obtain toxicity and similar symptoms with pure chemicals added to the growth medium.
4. Monitor release of allelochemicals from donor plants, detect them in the envir onment and ideally find them in a receiver plant.

These four steps in allelopathy research is necessary both for creditability and for getting a closer understanding what allelopathy is all about. This paper concentrates on research approaches for discovery and validation of allelopathy findings, with special attention to utilization of selective allelopathic potential in rice.

Discovery

Allelopathy is the direct influence of a chemical released from one plant on development and growth of another. This definition underscores the problem scientists face in allelopathy research: The compound causing the allelopathic effect has to be released from a plant, taken up by another plant, and cause changes in the development pattern of that plant. Development of a weed-fighting rice cultivar, able to control major weeds by itself, requires good methodology in the research process as the first step.

Bioassays are needed both in screening for allelopathic potential and in extraction and purification of allelochemicals. Design of a bioassay system, should be aimed to create a natural system. Allelochemical concentration should range around concentrations found in nature. Too high concentration could lead to wrong conclusions as all chemicals are poisonous, only the concentration determines the level of response. The same argument could be brought up for osmotic strength - a too high osmotic strength will *per se* inhibit germination and plant growth no matter which chemical compound is causing it.

A large screening of a germplasm collection is time and space consuming and success and reliability of the test species is important in terms of number of replications and statistical analysis. Therefore, it is of interest to include easily grown, sensitive, and reliable species in a first step of a screening procedure. *Lemna*, lettuce (*Lactuca sativa*) and radish (*Raphanus sativus*) are examples of easily grown and often used test plants in allelopathy studies (Leather & Einhellig, 1985; Einhellig *et al.*, 1985; Putnam *et al.*, 1983; Fujii, 1992). These plants were shown to be sensitive for chemical disturbance where, for example, measurement of chlorophyll content in *Lemna minor* was able to detect allelochemicals at a concentration above 0.5 ≤M (Einhellig *et al.*, 1985). The problem of using *Lemna*, lettuce, or radish is that they are of no agronomic importance as weeds and therefore allelopathy findings have to be confirmed on weed species as well.

Within allelopathy research, germination tests have been used in almost all experiments. Even though germination tests are common, there is need to ensure quality of results. Firstly in vitro germination is not applicable to all plant species. There is no problems with domesticated plants but weeds often germinate poorly and slower *in vitro*. If germination percentage is less than 50% the number of replicates needed to ensure good quality data is too high. Secondly, number of seeds per petri dish have to balance statistical needs with the fact that seeds response to allelochemicals in terms of amount of available allelochemical per seed (Weidenhamar *et al.*, 1987). Thirdly, the evaluation methodology has to be considered. One way of determining germination speed is to calculate the germination index as described by Pande, Dublish and Jain (1980) Germination was recorded daily for 5 days and the index was calculated as $I= 2(5x+4x+3x+2x+x)$ where x is the number of germinated seeds within each 24 hour period; $5x = 24$ hours count, $4x = 48$ hours count, etc. Another statistically correct, and equally good, method is to measure cumulative germination over time. This results in a logistic curve that can be tested in nonlinear regression analysis (Lehle & Putnam, 1982). With this approach treatments can be tested over a whole range of times and concentrations. Differences will graphically show out as horizontal or vertical displacement of the germination curve (Streibig, 1992). Measuring radicle elongation is another very common way of measuring early growth inhibitions. Radicle elongation, however seems to be a less sensitive method in allelochemical research but direct chemical disturbance such as pruning of root tips will show up in these experiments and thereby enable to distinguish allelopathic effect from competition.

Another problem in allelopathy research is obtaining of test solution. The problem is often solved by extracting plants or plant parts with water, but such extracts can give a concentrated assay material with an osmotic potential not always within the "no effect level" (Wardle *et al.,* 1992; 1993). Using plant extracts also addresses another problem. The fact that an allelochemical is inside a plant does not necessarily mean that the plant is able to exude or leach it into the environment where it is available for other plants (Perez, 1990; Perez & Ormeno-Nuñez, 1993).

Exudate traps can be used to provide a test solution actually released from the plants. One way of exudate trapping is the use of hydroponics, where donor plants are grown in a nutrient solution that is changed periodically. The nutrient-exudate soup can thereafter be used as the test solution in a bioassay. Hydroponics has been used successfully for evaluating allelopathic potential in barley (*Hordeum vulgare*) using *Sinapis alba* as test plant (Liu & Lovett, 1993). Depending on the length of the assay and the growth parameters measured, the test solution requirements vary from 40 to 170 ml (Leather & Einhellig, 1986). This is a large amount of solution, which makes hydroponics useful only in initial screening programs.

Whole plant bioassays are often very space consuming and therefore not applicable in large screening programs. Pope, Thompson and Cole (1985) described an interesting technique: They used PVC pipes and fittings. Plants were sowed in a mixture of sand and soil in T-fittings or drilled holes. The system was overwatered and exudate solution was collected at the open end of the pipe and used as test solution.

Validation

After clear indications of allelopathic activity in well-conducted bioassays, there is need to validate the findings. Validation should include purification of the chemicals causing the allelopathic effect and experiments on how those chemicals act to give the effect. But validation should also include setting criteria for breeders to work with in creating an allelopathic rice cultivar.

Purification of allelochemicals requires extraction procedures that avoid loss of the small amount of allelochemicals. Therefore, techniques enable to detect allelochemicals in a test solution are preferable, e.g. HPLC (High Performance Liquid Chromatography) or gas chromatography. After identifying the allelochemicals actually in the test solution, pure chemicals must be tested for activity.

Many research report list phenolic acids as inhibiting plant development. Phenolic acids are among the putative allelochemicals in rice and have been shown to cause autointoxification in double rice cropping systems (Chou, 1987). However, no researcher has been able to follow these phenolics from release by a rice plant to uptake in another plant. One reason could be that allelochemicals work synergistically and thereby cause an allelopathic effect (Einhellig *et al.,* 1982; Rice, 1987). This needs to be confirmed by assays of pure chemicals alone and in mixtures. Because there are several suspected chemicals this task involves a lot of stepwise mixtures. Working with joint action of chemicals raises many questions. Firstly, the kind of joint action has to be determined. In a mixture of two components this can be stated as follows (Streibig, 1992):

1. Only the combination of the two components is biologically active.
2. Only one of the components are biologically active but presence of the other one affect the level of activity.
3. Both components are independently biologically active.

In our allelopathy research we assume that the allelochemicals we are looking for have independent biological activity. This assumption needs to be confirmed and can be done by establishing individual dose response curves for all the putative allelochemicals. After that the mixing of chemicals can start based on effect level and not on concentrations.

The easiest way of testing mixtures is to use the Additive Dose Model (ADM). It assumes that one effect level can be added to another resulting in a sum of effects. This means that a mixture of two components, where both are given in a dose responding to 50% control, will result in 100% control. If the effect of the mixture does not fit the additive assumption there must be interactions, either synergistic or antagonistic. If two chemicals produce their effect in entirely different ways (different mode of action) ADM will not be able to describe our data. The Multiplicative Survival Model (MSM) was developed to describe joint actions in mixtures of chemicals with different mode of action (Morse, 1978). MSM is also based on dose response curves for the chemicals applied alone, but MSM requires that responses are expressed as a proportion of a maximum-value. MSM is also dependent on the effect level under study and will change as the choice of effect level changes (Streibig, 1992). Because the putative allelochemicals in rice are all phenolic acids it seems reasonable to assume similarities in their mode of action (Hsu *et al.*, 1989). Therefore an assumption of additive effects also seems reasonable.

Allelopathic activity is validated if allelochemicals are found and characterized and if toxicity with similar symptoms is achieved with pure allelochemicals applied alone or in mixtures. Activity is further validated when a researcher is able to follow allelochemicals from release from rice to site of action in another plant using, for example, radioactive labeled material.

Concluding remarks

In a discussion on approaches in rice allelopathy research it is important to include comments on what kind of allelopathic rice we want. Primarily, there is need for allelochemicals to be released at a proper time in a proper concentration in the field. A proper timing in rice would be early growing stages, when weeds establish and create the basis for a later weed problems. The crop is also most sensitive to competition in the early vegetative growth. Finally, these development stages determine the possible crop yield at the end of the season. There is also need for allelochemicals with a broad spectrum activity, able to fight many weed species, but still, without affecting the rice crop. Because rice straw has phytotoxic properties, any increase in phytotoxic compound could cause problems for following crops. Therefore it is of highest importance that ecotoxicological features of the allelochemicals are studied from release to degradation.

Research on allelopathic rice cultivars aims to develop plants that will reduce the need of chemical inputs but not create new environmental problems. Research to achieve the goal of a weed fighting rice cultivar, must be multidiciplinary. Complexity of allelopathy makes it necessary for weed scientists to work in close collaboration with plant physiologists, plant biochemists, soil scientists, and plant breeders.

Developing allelopathic rice cultivars is not an easy task but a very challenging one and the dream of a weed fighting cultivar is worth fulfilling.

References

Chou C.H. 1987; Allelopathy in sustainable agriculture in Taiwan. *Proceedings of the 11th Asian-Pacific Weed Science Society Conference*, Taipei, Republic of China. 1-11.

Duke S.O. 1985; Biosynthesis of phenolic compounds- Chemical manipulation in higher plants. *The chemistry of allelopathy: Biochemical interactions among plants* (Ed. A.C. Thompson). 113-131.

Einhellig F.A., Leather G.R., Hobbs L.L. 1985; Use of *Lemna minor* L. as a bioassay in allelopathy. *Journal of Chemical Ecology.* **11(1):** 65-72.

Einhellig F.A., Schon M. K. ,. Rasmussen J. A. 1982; Synergistic effects of four cinnamic acid compounds on grain sorghum. Journal of Plant Growth Regulation. **1:** 251-258.

Fuerst E.P., Putnam A.R. 1983; Separating the competitive and allelopathic components of interference: Theoretical principles. *Journal of Chemical Ecology.* **9(8):** 937-944.

Fujii Y. 1992; The potential biological control of paddy weeds with allelopathy - Allelopathic effect of some rice varieties. *Proceedings of international symposium on biological control and integrated management of paddy and aquatic weeds in Asia.* 305-320.

Gliessman S.R. 1982; Allelopathy and biological weed control in agroecosystems. *Proce edings of the seminar on Allelochemicals and Pheromones.* 77-86.

Hsu F-H., Chiu C-Y,. Chou C-H. 1989; Action model of allelopathic compounds on seed germination. *Phytochemical ecology: Allelochemicals, mycotoxins and insect pheromones and allomones* (C. H. Chou & G.R. Waller, Eds.) Academica Sinica Monograph Series. No. **9:** 315-327.

Leather G.R., Einhellig F.A. 1985; Mechanisms of allelopathic action in bioassay. *The chemistry of allelopathy: Biochemicals interactions among plants.* ACS symposium series nr. 268 (Ed. A.C. Thompson). 197-205.

Lehle F.R., Putnam A.R. 1982; Quantification of allelopathic potential of Sorghum residues by novel indexing of Richards' function fitted to cumulative cress seed germination curves. *Plant Physiology.* **69:** 1212-1216.

Liu D.L., Lovett J.V. 1993; Biologically active secondary metabolites of barley. II. Phytotoxicity of barley allelochemicals. *Journal of Chemical Ecology.* **19(10):** 2231-2244.

Morse P.M. 1978; Some comments on the assessment of joint action in herbicide mixtures. *Weed Science.* **29**:58-71.

Pande P.C., Dublish P.K., Jain D.K. 1980; Effects of extracts of *Agremone mexicana* Linn. on seed germination and seedling growth of *Abelmoschus esculentus* Ser. *Bangladesh Journal of Botany.* **9(1):** 67-71.

Perez F.J. 1990; Allelopathic effect of hydroxamic acids from cereals on *Avena sativa* and *A. fatua. Phytochemistry.* **29(3):** 773-776.

Perez F.J., Ormeno-Nunez J. 1993; Weed growth interference from temperate cereals: the effect of a hydroxamic-acid-exuding rye (*Secale cereale L.*) cultivar. *Weed Research.* **33:** 115-119.

Pope D.F., Thompson A.C., Cole A.W. 1985; Phytotoxicity of root exudates and leaf extracts of nine plant species. *The chemistry of allelopathy: Biochemical interactions among plants.* ACS symposium series nr. 268 (Ed. A.C. Thompson). 220-234.

Putnam A.R., DeFrank J., Barnes J.P. 1983; Exploitation of allelopathy for weed control in annual and perennial cropping systems. *Journal of Chemical Ecology.* **9(8):** 1001-1010.

Streibig J.C. 1992; *Quantitative assessment of herbicide phytotoxicity with dilution assay.* Copenhagen, Denmark, Royal Veterinary and Agricultural University. 98 p.

Rice E.L. 1987; *Allelopathy: An overview. Allelochemicals: Role in agriculture and forestry.* ACS symposium series nr. 330. (Ed. G.R. Waller). p 8-22.

Wardle D.A., Nicholsen K.S., Ahmed M. 1992; Comparison of osmotic and allelopathic effects of grass extracts on grass seed germination and radicle elongation. *Plant and Soil.* **140:** 315-319.

Weidenhamer J.D., Morton T.C., Romeo J.T. 1987; Solution volume and seed number: often overlooked factors in allelopathic bioassays. *Journal of Chemical Ecology.* **13(6):** 1481-1491.

In Vivo and In Vitro System for Bioassay of Allelopathic Substances In Rye (*Secale Cereale* L.)

Yu, Chang-Yeon [1*], E Hun Kim[2], and Jang-Hyun Hur[3]

1 Dept. of Plant Resources, Kangwon National University, Chuncheon 200-701, Korea
2 Dept. of Agronomy, KNU, 3 Dept. of Agricultural chemistry, KNU, Chuncheon 200-701

Abstract. Experiments were conducted to determine the effect of rye allelopathic effect in callus growth and weed germination using *in vitro* and *in vivo* systems. Callus induction and growth of several weeds were inversely proportional to the concrntration of rye water extracts on Murashige and SKoog medium with 2,4-D 2mg/l. The degree of inhibition ranged from 50 to 90 %, compared with that of control. When the dried rye plants were mixed into soil, higher concentration (above 10%) of plant mixtures remarkably inhibited the germination rate, shoot length, and weight of several weeds such as *Siegesbeckia pubescens* M., *Solanum nigrum, Digitaria saguinalis, Setaria faberi, Chenopodium album* L., and *Portulaca oleracea* L.. Water extracts of rye plants also showed strong inhibition effect on germination and seedling growth of several weeds. Allelochemicals from rye were analysed using gas chromatogram and phenolic compounds were detected.

Key words : Allelopathy, Rye, In vitro, In vivo system

Introduction

Allelopathy is the detrimental effects of allelopathy chemicals from a donor plants on the growth or development of a receptor plant. Alleochemicals are generally secondary plant metabolites, part of a wide range of chemicals synthesized by the plant which are not directly involved in plant growth and development. The biological activity of allelochemicals depend on the presence of sensitive plant species, the combination of allelochemicals, their toxicity, and their length of persistence (Einhelling and Ekrich, 1984). Weed suppression by allelopathic plant residues results from a conbination of allelopathy and physical factors as reductions in tillage and radiation. Residues, tillage practices, and crop sequences all can be managed to optimize allelopathic weed control (Barnes and Putnam, 1986). Environmental conditious play a major role in allelopathec interaction. Allelochemicals accumulate at or near the soil surface in no-till or conservation tillage systems, where rain or irrigation leach them from the crop residues (Rice, 1984).

Winter rye is one of the better allelopathic cover crops because it over winters well and produces considerable biomass (Barns and Putnam, 1986). Weed suppression by rye residues lasts for 30 to 75 days depending on soil and weather conditions (Barnes and Putnam, 1983). Generally,residues are most toxic to broadleaf weeds, moderately toxic to grasses and have little or no effect on perennial weeds (Barns and Putnam, 1986). Rye cover in no-till vegetable production systems can reduce total weed biomass by 95% when compared to controls without residues. Rye have been observed to be allelopathec, althought, its management in reduced tillage systems remains unclear. Several reports demonstrate the allelopathic effects of rye.(Barns and Putnam, 1983, 1986; PrzepiorKowski and Gorsk, 1994)

In vitro system could be offer a number of advantages for studying the effect of allelopathic substances. In vitro cultures provide both a uniform growth environment and uniform exposure to allelopathic substances. Thus, this experiments were conducted to determine the effect of rye allelopathic effect in callus growth and weed control using in vitro and in vivo systems.

Materials and Methods

In vitro bioassay

Weeds were surface sterilized in 10% sodium hypochlorite for 10 minutes and washed three times in sterilized distilled water. Explants were cultured on the petri dishes containing Mushige & skoog medium, 0.7 % agar, 3 % sucrose, and 2,4-D 1mg/l. The allelopathic substances exudated from rye plants were added into the medium and the explants incubated under fluorescent white light at 25℃ under the day light for 24 hrs. At the end of a 4 week period, the fresh weight of callus was recorded.

Effect of rye residue mixtures in soil and rye extracts on germination of weeds

Rye plants harvested from field on early June were dried in laboratory for 1 weeks. The dried plants were crushed by grinder. The grinded rye plants were mixed into pot (16.5 × 8 × 7 cm) containing vermiculite by the concentration 0, 0.1, 1, 10, 20% (w/w). Twenty weed seeds of hairy crabgrass (Digitaria Sanguinalis), green foxtail (Setaria viridis), blacknightshade (Solanum niigrum), common purslane (portulaca oleracea L.), and St. Pulswort (Siegesbeckia Pubescens Macino) were planted on pot. The germinated seeds were counted daily. The shoot weight and length, root weight, and root length were recorded after 3 weeks. The dried plants were extracted with distilled water for 24 hours and filtered, and centrifuged at 3000 rpm for 15 minutes. The upper solution was used for bioassay of several weeds.

Indentification of allelochemicals.

A gas chromatography (Hewlett packard 5890, U.S.A) with F.I.D 5% SE-30 column was employed for analysing the phenol compounds from rye extration. Identification of each peaks was made by the comparison of retention times of the peaks with those of commercial compounds obtained from Sigma company.

Results and discussion

In vitro bioassay

When allelopathic substances extracted from ryes were treated on medium, callus growth of several weeds was inhibited. The degree of inhibition differed depending on weed species and the level of extraction substances. The extracts of above 5% rye inhibited the callus growth of several weeds and the inhibition rate ranged from 50 to 90%, compared with that of control (Table 1). Kil et al., (1993) also reported that water extracts of Pinus koraiensis inhibited the induction and growth of callus in Murashige and Skoog medium

Table 1. Fresh weight of several weed callus grown on the medium containing different concentrations of allelopathic extracts from Rye plants.

Concentration		*D. sangunalis*	*C. album*	*A. lividus*	*P. oleranea*	*C. communis*
Control(g/callus)		0.20	1.10	0.20	1.10	1.14
Rye	0.1%	95.0*	54.5	150.0	72.0	104.0
	5 %	30.0	25.4	50.0	18.2	11.4
	10 %	30.0	9.0	25.5	36.4	43.9

* The percent concentration represents % fresh weight of control.

Effect of rye residue mixtures in soil and the aqueous extract on germination.

Dried rye mixtures in soil inhibited the germination of hairy crabgrass, green foxtail, black nightshade, common purslane, and St. paulswort (Table 2). As the concentration of allelopathic plants increased, the germination rate was decreased. At the treatment of 20% dried rye plants, the rate of gremination in hairy crabgrass and asiatic dayflower was 60 and 65%, respectibly, while that in common purslane and livid amaranth was 10%. Also, mixtures of 10% dried rye plants inhibited the growth of shoot and root (Table 3). Higher concentration (above 10%) of dried rye plants remakably inhibited the shoot length, shoot weight, root length, and root weight, indicating that rye plants contain the allelochemicals inhibiting the germination, and plant growth of several weeds.

Table 2. Effect of dried rye mixtures into the soil on the germination of different weeds after 3 weeks.

Concentration (%)		seed germination (%)				
		D. sangunalis	*C. album*	*A. lividus*	*P. oleranea*	*C. communis*
Contorl		95	80	70	95	100
Rye	1	90	65	70	90	80
	10	55	30	60	55	60
	20	60	35	10	10	65

Table 3. Effect of dried rye mixtures into the soil on the shoot and root growth of different weeds.

Concentration(%)		*D. sanguiralis*		*S. viridis*		*S. pubescens*		*P. oleracea*		*S. nigrum*	
		Shoot growth									
		SL[1]	SW[2]	SL	SW	SL	SW	SL	SW	SL	SW
Control		136	153	17	186	48	150	19	78	30	45
Rye	1	102	145	122	192	32	70	14	19	8	42
	10	52	49	111	175	52	78	15	47	8	18
	20	60	49	87	66	7	15	7	2	7	5
		Root growth									
		RL[3]	RW[4]	RL	RW	RL	RW	RL	RW	RL	RW
Control		83	24	140	58	30	90	10	3	37	9
Rye	1	53	41	66	45	56	43	5	4	27	7
	10	48	20	75	67	44	60	6	5	25	4
	20	22	10	47	48	4	1	3	0	5	1

1. SL : Shoot length (mm/seedling)   3. Rl : Root length (mm/seedling)
2. SW : Shoot weight (mg/seedling)   4. RL : Root weight (mg/seedling)

Allelopathic substances extracted dried rye plants also inhibited germination shoot length, and shoot weight of several weeds (Table 4 and 5).

Table 4. Effect of allelopathy substance exudated from dried rye on the germination of several weeds after 10 days.

Concentration(%)		Seed gernination (%)			
		D. sanguiralis	*S. pubescens*	*S. nigrum*	*A. livedus*
Control		88	85	85	65
Rye	0.1	78	67	90	95
	1	60	97	72	25
	10	42	0	0	20

Table 5. Effect of allelopathy substance exudated from dried rye on the shoot growth of several weeds after 10 days.

Concentration(%)		*D. sanguiralis*		*S. pubescens*		*S. viridis*		*P. oleracea*		*E. crus-galli*	
		SL	SW	SL	SW	SL	SW	SL	SW	SL	SW
Control		49	83	11	139	26	4	15	15	53	10
Rye	0.1	46	86	15	142	37	4	16	18	31	4
	1	42	66	12	129	13	2	5	5	35	7
	10	19	62	3	10	0	0	9	7	30	6

1. SL : Shoot length (mm/seedling)
2. SW : Shoot weight (mg/seedling)

Identification of allelochemicals.

Allelochemicals in two rye cultivars, Paldang and Singi were detected using gas chromatography by comparison of retention time of standard phenol compounds (Table 6). The amounts of phenol compounds differed depending on the rye cultivar, and plant parts. In general, the amounts of phenol compounds in cv. Paldang as much higher than that in cv. Singi. Shoot parts of rye contained higher concentration of phenol compounds than that of other root part. Our results indicate that phenolic compounds are one of allelochemicals which inhibit germination, plant growth, and development of weeds. We can use in vitro and in vivo system for bioassay of allelochemicals. Futuire studies with weeds will investigate the allelopathic effect of rye in a field setting.

Table 6. Phenol compounds of different rye cultivar analysed by gas chromatography.

Rye	Salicylic acid	Hydroxy benzoic	Vanillic acid	Syringic acid	Coumaric acid	Ferulic acid
(cv. Paldang)						(ppm/5g)
Shoot	1,492	1,286	1,354	1,506	1,392	292
Root	383	437	311	7	752	57
(cv. Singi)						
Shoot	479	278	410	117	1,085	98
Root	358	351	403	98	1,065	162

References

Banks, P. A. 1984. Allelopathic crops: potential aid in weed control. Crops and Soils magazine 3:18-19 ASA. Madison, WI

Barns, J. P. and A. R. Putnam. 1986. Evidence of allelopathy by residues and aqueous extracts of rye (Secale cereale L.). Weed Science 34:384-390.

Barns, J. P. and A. R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. Chem.Ecol. 9:1045-1057.

Einhelling, F. A. and P. E. Ekrich. 1984. Interaction of temperature and ferulic acid stress on grain sorghum and soybeans J. Chem. Ecol. 10:161-170.

Putnam, A. R. 1986. Allelopathy : Can it be managed to benefit horticulture; Hortsci. 21:411-412.

Putnam, A. R.1988. Allelochemicals from plants as herbicides. Weed Technol. 2: 510-518.

Putnam, A. R., J. Defrank, and J. P. Barns.1983. Exploitation of allolopathy for weed control in annual and perennial cropping systems. J. Chem. Ecol. 8:1001-1010.

Przepiorkowski, T. and S. F. Gorsk, 1994. Influence of rye (Secale cereale) plant residues on germination and growth of three triazine-resistant and susceptible weeds. Weed Technol.

PHYTOTOXIC COMPOUNDS FROM *ANAXAGOREA LUZONENSIS*

Vilai Santisopasri*, Michiko Sato, Shigeru Tamogami,
Yumiko Nakazato, Masaaki Kitahara, and Osamu Kodama
*Faculty of Science, KASETSART UNIVERSITY, Bangkok, Thailand
School of Agriculture, IBARAKI UNIVERSITY, Ami, Ibaraki 300-03, Japan

Abstract

We found that the extract of *Anaxagorea luzonensis* showed effective phytotoxic activity against *Raphanus sativus* and *Echinochloa utilis*. We purified the phytotoxic compound and elucidated its structure as 3,4-dihydroxy-2'-methoxy-benzophenone. This compound inhibited both root and shoot elongation of *Raphanus sativus*, whereas it inhibited only root growth of *Echinochloa utilis* at concentrations greater than 200 ppm.

key words

Anaxagorea luzonensis, Raphanus sativus, Phytotoxic compound, Benzophenone

Introduction.

Higher plants produce several bioactive compounds that affect the growth of diverse organisms. Among these bioactive compounds, phytotoxic compounds are important as templates for synthetic herbicides. This prompted us to search for phytotoxic compounds among tropical plants which survive intense competition for growth and development. Upon examining phytotoxic activity in crude extracts from several tropical plants, we found that the extract of *Anaxagorea luzonensis* showed effective phytotoxic activity against *Raphanus sativus* and *Echinochloa utilis*. This result encouraged us to isolate phytotoxic compounds from this plant.

Materials and methods

Bioassay

Seeds of *Raphanus sativus* and *Echinochloa utilis* were placed on filter paper moistened with dilutions of extracted active compounds in plastic cups and were incubated in light at 25°C for one week. Germination and radicle growth of the seeds were then evaluated relative to control seeds moistened with a solution of 0.2% methanol in water.

Extraction and purification of active compounds.

Approximately 500g, dried plant of *Anaxagorea luzonensis* was extracted with 70% methanol, and the resulting aqueous solution partitioned in ethyl acetate. Ethyl acetate fraction was evaporated to yeild 20g of crude extract. The active compound was purified by silica gel column chromatography separation (benzene : ethyl acetate = 10 : 1) and HPLC purification (Reversed phase C-18; Cosmosil 5C18-AR) to give 3.5mg of active compound. Isolation scheme is shown in Fig. 1.

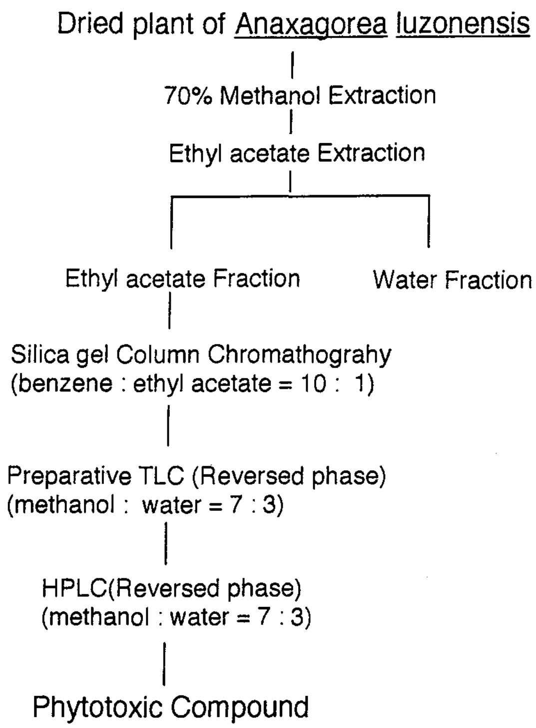


Fig.1. Isolation Scheme of Phytotoxic Compound.

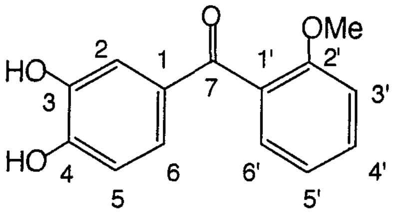
Structure Elucidation

Structure elucidation of the active compound was done by MS, IR, UV and NMR studies.

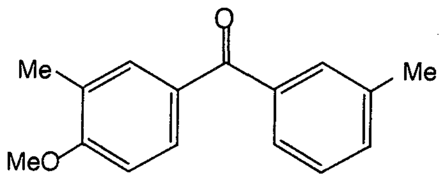
Results and Discussion

Properties of the active compound are as follows : molecular weight; 244, molecular formula; $C_{14}H_{12}O_4$ (HR-EIMS), IR; 3420 cm^{-1}, 1650 cm^{-1}, UV(λ max) 290 nm. The ^{13}C-NMR spectrum of the compound shows peaks for 14 carbons. The ^{13}C-NMR indicates that one carbonyl carbon and 8 aromatic carbons and 3 oxygenated aromatic carbons are present. The ^{1}H-NMR shows methoxy group and 7 aromatic protons in this compound. These data suggested that this compound is a benzophenone derivative, which has two hydroxy and one methoxy substitutions. Further long range coupling experiments validated the structure of this phytotoxic compound as 3,4-dihydroxy-2'-methoxy benzophenone (1). This compound inhibited both shoot and root growth at more than 200 ppm against *Raphanus sativus* , whereas it inhibited only root growth in *Echinochloa utilis* . Some synthetic benzophenone derivatives are known for their herbicidal activities. The 4-methoxy-3,3'-dimethylbenzophenone((2), commercialname; Methoxyphenone) has been used in paddy fields as a herbicide [1]).

These synthetic benzophenone derivatives showed stronger inhibition against root than shoot growth of barnyardgrass [1]. This selective inhibition between root and shoot is also the case of the benzophenone compound (1) isolated from *Anaxagorea luzonensis. Anaxagorea luzonensis* yielded two other phytotoxic compounds on HPLC analysis. Purification and structural elucidation of these compounds are now in progress.



(1)



(2)

References.

1) Yamada O, Kurozumi A, Futatsuya F, Ito K, Ishida S and Munakata K, 1979, Studies on Chlorosis-inducing Activities and Plant Growth Inhibition of Benzophenone Derivatives., Agric. Biol. Chem., 43, 1467-1471.

Genetic Stability of Resistance of Bean (*Phasedus Vulgaris L.*) to Glyphosate

Tao Bo   Qin Zhiwei

(Northeast Agricultural University, Harbin 150030, China)

Abstract: In this paper thirty lines of bean were tested for resistance to glyphosate in the field. Obvious difference in resistance response to glyphosate was detected, when glyphosate was applied at the rate of 1kg ai / ha on the 15th day after emergence of seedlings. The line 89–05 showed high resistance with a survival of 77%. Even after glyphosate was reapplied, the survival rate was still 20%. Obvious segregation was found in Progency of 89–05 for resistance to glyphosate; the survival rate of lines 89–05–1 89–05–2 and 89–05–3 were, respectively, 42.3%、 51.4% and 85.7% at 1kg ai / ha of the herbicide. Progenies 89–05–3 continued to show resistance and lines 89–05–3–5 and 89–05–3–7 both had a survival rate of 100%. When glyphosate was applied with a rate over 1kg ai / ha, the survival rate of the 89–05–3–5 was still between 50～98%.

Key Words: Glyphosate   Stability   Bean   Risistance

Introduction

Selection for resistance to non–selective herbicide in crop plants is a new approach to developing selective weed control. Glyphosate [N–(phosphonomethyl) glycine) is a broad spectrum nonselective herbicide which is highly effective yet poses minimal environmental risk[1], Tolerance to glyphosate has been reported in bacteria: typhimurium[2] and Acrobacter aerogenes[3] and willian E. Dyear et al. [4] reported Glyphosate to Tolerant tobaco cell variants, but so far no resistance of bean to glyphosate is reported.

In this paper, thirty lines of bean were tested for resistance to glyphosate in field, and their stability was studied.

Materials and Methods

Glyphosate (N–(phosphonomethyl) glycine was provided from Monsanto Company (Roundup WS 41%).

Thirey bean lines from the Department of Horticultural of Northeast Agriculture University.

Seeds of thirty lines of bean were sown in pots (12× 12cm), 35 pots was sown for one line and 3 seeds in one pot. Dosage of 1kg ai / ha glyphosate was sprayed on the 15th day after emergence of the seedlings. Repeated spraying with the same rate on the 35th day after emergence was conducted. Residual plants in progenes of the tested line were selected for further study.

Resistance to glyphosate was compared among different generation with three rates (1、 1.5、 2kg ai / ha) applied on the 15th day afteremergence of bean.

Results and Discussion

一、 Resistance responce to glyphosate of bean lines

Bean lines showed obvious diference in resistance response to glyphosate (Table 1). When glyphosate was applied at the rate of 1kg ai / ha on the 15th day afteremergence of the seedlings. Line 89–05 showed high resistance with a survival rate of 77%, even after glyphosate was reapplied, the survival rate was still 20%. Lines 90–15、 90–10、 90–16 and 89–17 also showed considerable resistance to glyphosate, the survival rate was 20～ 51.4% after first treatment and 5.7～10% after the second, but growth of these lines was inhibited. The other lines were heavily damaged in the first treatment, all were killed in the second treatment. This showed that resistance to glyphosate existed in bean.

Table 1. Different lines of bean in resistance responce to glyphosate (rate 1kg ai / ha)

Lines	Number of Seedling	Survival of First Treatment	Survival rat (%)	Survival of second treatment	Survival rate (%)
89–05	35	27	77	7	20
90–15	35	18	51.4	4	10
90–10	35	13	37	3	8.5
90–16	35	8	22.9	3	8.5
89–17	35	7	20	2	5.7
92–16	35	10	28.6	0	0
89–07	35	9	25.7	0	0
90–32	35	6	17.1	0	0
91–032	35	5	14.2	0	0
92–08	35	4	10.4	0	0
90–07	35	3	8.5	0	0
90–09	35	3	8.5	0	0
92–03	35	3	8.5	0	0
89–23	35	3	8.5	0	0
89–10	35	2	5.7	0	0
89–13	35	1	2.8	0	0
90–04	35	1	2.8	0	0
90–05	35	1	2.8	0	0
91–010	35	1	2.8	0	0
92–11	35	1	2.8	0	0
89–11	35	1	2.8	0	0
91–001	35	1	2.8	0	0
91–003	35	1	2.8	0	0
91–009	35	0	0	0	0
91–011	35	0	0	0	0
91–041	35	0	0	0	0
92–01	35	0	0	0	0
92–13	35	0	0	0	0
92–14	35	0	0	0	0

二、 Genetic Stability of bean in resistana to glyphosate

Obvious segregation was found in progenies derived from line 89–05 for resistance to glyphosate (Fig. 1); the survival rate of lines 89–05–1, 89–05–2 and 89–05–3 was, respectively 51.4%、 40% and 85.7%; at the rate of 1kg ai / ha of glyphosate in the first treatment, and 8.5%、 10% and 42.9% in the second treatment. but these lines all showed high resistance to glyphosate, specially, resistance of line 89–05–3 was higher than that of its parent 89–05. Resistance of lines 89–05–1 and 89–05–2 was lower than its parent 89–05.

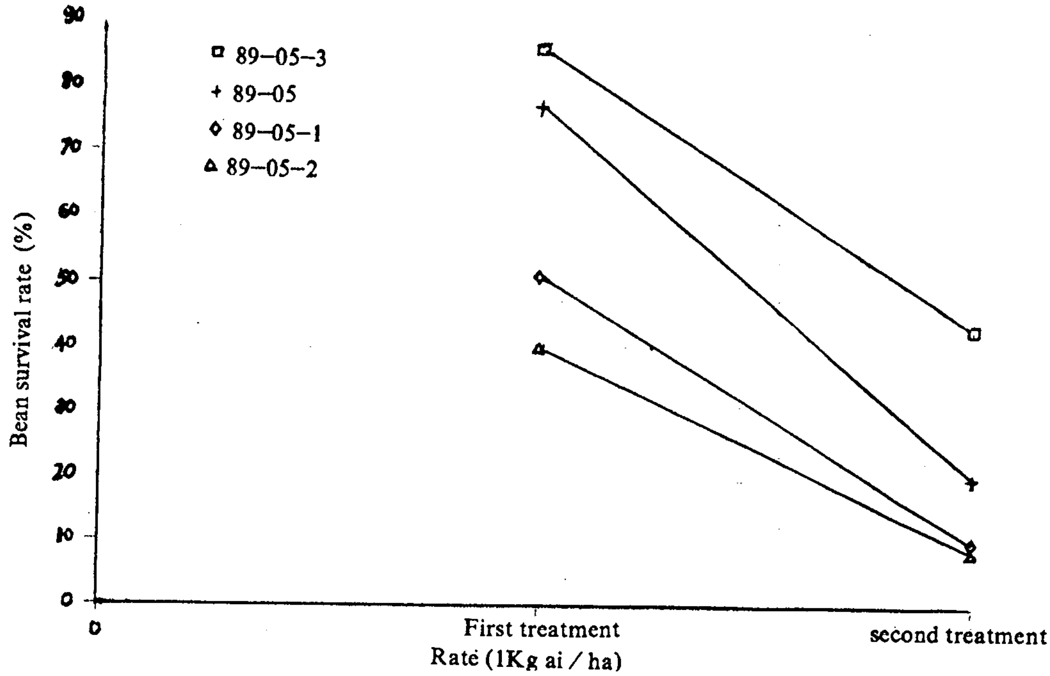


Fig.1 Progenies of line 89–05 in resistance response to glyphosate

More obvious segregation of resistance to glyphosate was found lines derived from lines 89–05–1 89–05–2 and 89–05–3 (Table 2.). Resistance of progenies derived from 89–05–1 and 89–05–2 was lower that of the initiated line 89–05. No high resistance line could be selected Progenies derived from 89–05–1 and 89–05–2. From 8 progenies of 89–05–03, the survival rate of six lines was reached more than 50%, and lines 89–05–3–5 and 89–05–3–7 both had a survival rate of 100%. The growth of both lines was not affected by glyphosate. This meaned that resistance genetic of bean to glyphosate becomes stable by selection.

Table 2. Progenies of 89–05–(1,2,3) lines of bean in resistance responce to glyphosate (rate 1kg ai / ha)

Lines No.	Number of seedling	Survival	Survival rate (%)
89–05–1–1	35	6	17.1
89–05–1–2	35	15	43.75
89–05–1–3	35	25	71.4
89–05–2–1	35	11	31.4
89–05–2–2	35	20	57.1
89–05–2–3	35	9	25.7
89–05–3–1	35	8	22.9
89–05–3–2	35	21	60.0
89–05–3–3	35	20	57.1
89–05–3–4	35	14	40
89–05–3–5	35	35	100
89–05–3–6	35	25	71.4
89–05–3–7	35	35	100
89–05–3–8	35	19	54.2

三、Bean resistance to different dosage of glyphosate

Representative bean lines were tested for their resistance to different dosage of glyphosate. The results showed that with increase of the dosage of glyphosate the survival rate of the lines decreased (Fig. 2), but with increase of progenics of lines 89–05, the survival rate of the lines increased. When applied rate of glyphosate was increased from 1 to 1.5 and 2 kg / ha on the 15th day after emergence of seedlings. The survival rate of line 89–05–3–5 decreased from 98%to 80% and 50%. This showed that the stable bean line of resistance to glyphosate decreased much less than their parent lines and kept their high resistance.

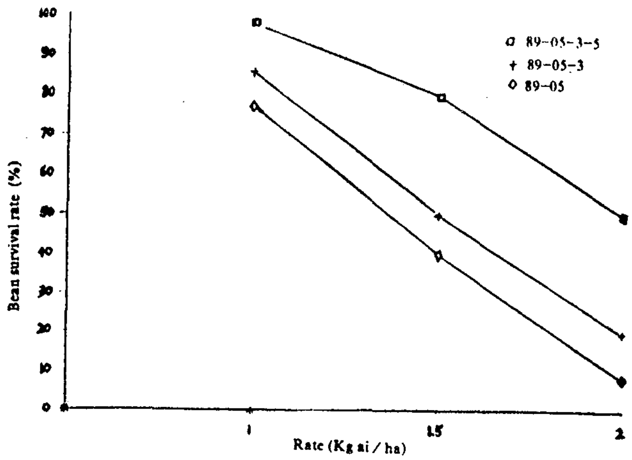


Fig.2 Different lines of bean in resistapse extant to glyphosate

Acknowledgment: The authors wish thank of prof. Wu Yingxiang and prof. Su Shaoquan for critical reading of the manuscript.

References

[1] GROSSBARDE. DATKINSON 1985 The Herbicide Glyphosate. Butter worths. London.

[2] COMAL. LC SEN DM STALKER 1983 An altered aroA gene product confers resistance to the herbicide glyphosate. Science 221: 370–371.

[3] SCHULZ A. D SOST. N AMRHEIN 1984 Insensitivity of 5–enolpyruvglshikimic acid–3–phosphate synthase to glyphosate confers resistance to this herbicide in a strain of Aerobacter aerogenes. Arch Microbiol 137: 121–123.

[4] WE DYER. SC WELLER. RA BRESSAN 1988 Glyphosate Tolerance in Tobacco. Plant Physiol. 88: 661–666.

Response of Chlorsulfuron-Resistant Rapeseed Mutants to Acetolactate Synthase Inhibitors

F. Dastgheib, R.J. Field and A.J. Conner

Department of Plant Science , Lincoln University, New Zealand

Abstract. Mutant lines of rapeseed (*Brassica napus* L.), produced through seed mutagenesis, have been selected with increased resistance to chlorsulfuron. One of these mutant lines tolerated rates of the herbicide up to 60 g a.i./ha with only 24 % reduction in fresh weight. In contrast, the wild-type plants showed more than 80 % reduction in fresh weight following chlorsulfuron applications as low as 1 g a.i./ha. Dose response curves established that one of the isolated lines was more than 360 times more resistant to chlorsulfuron than the wild-type. The resistant lines demonstrated cross resistance to tribenuron but not to imazapyr. Possible mechanisms of resistance are discussed.

Key words. *Brassica napus*, imazapyr, imidazolinone, sulfonylurea, tribenuron.

INTRODUCTION

Sulfonylurea and imidazolinone herbicides have received much attention during the last decade as potent herbicides with broad spectrum weed control activity. They are more environmentally acceptable than many conventional herbicides because of their low use rates and low mammalian toxicity (Beyer *et al.*, 1988; Stidham, 1991). Both groups of herbicides kill weeds by inhibiting the activity of acetactate synthase (ALS), the first enzyme in the biosynthetic pathway of branched chain amino acids (Ray, 1984; Stidham, 1991). A single primary site of action makes it easier to develop crop varieties with greater resistance to these herbicides. This will offer several applications in crop management including a wider choice for weed control and more flexibility in crop rotation (Field, Conner, and Foreman, 1993). Several plant mutants have been isolated with higher degree of resistance to ALS inhibiting herbicides (Hart, Saunders and Penner, 1992; Newhouse *et al.*, 1992; Magha *et al.*, 1993).

In a previous report (Conner *et al.*, 1994), we demonstrated the use of seed mutagenesis for developing mutants of a rapid cycling rapeseed (*Brassica napus* L.) with improved resistance to chlorsulfuron (Glean 750 DF), a sulfonylurea herbicide. This paper presents data on the response of two selected rapeseed mutants to varying doses of chlorsulfuron and to other ALS inhibitors.

MATERIALS AND METHODS

Dose response experiment

Two mutant lines of rape developed through seed mutagenesis which showed increased resistance to chlorsulfron (see Conner *et al.*, 1994 for details) were used in this experiment. The above lines, designated as 19c and 30a, were compared with the wild type for their response to different rates of chlorsulfuron. Seeds were germinated on moist paper towels and planted individually into 10-cm diameter pots filled with 4 parts composted bark: 1 part sand, supplemented with a base dressing of fertiliser. Plants were maintained in a controlled environment cabinet at 10 h daylength, 300 μ mol/m^2/s light intensity with day/night temperature of 20/10°C. When plants reached the four-leaf stage, they were sprayed with chlorsulfuron at different rates as given in Figure 1. Chlorsulfuron was sprayed using a CO_2 pressurised knapsack sprayer delivering 200 l water/ha at 300 kPa. The herbicide solution contained Citowett at a concentration of 0.25 ml/l. Visual evaluation of plant response as well as fresh and dry weight of shoots, were recorded 21 days after spraying (DAS).

Cross resistance experiment

Plant material and growing conditions were the same as in the dose response experiment. Plants were sprayed at the four-leaf stage with either tribenuron (Granstar 750 DF) at 15 g a.i./ha or imazapyr (Arsenal 250 EC) at 250 g a.i./ha as described above. Unsprayed control plants were included in the experiment. Shoot fresh weight and dry weight values were taken as above.

Experimental design and statistics
A randomised complete block design with five replicates was used for both experiments. All data were subjected to analysis of variance. In the dose response experiment, percentage reduction values in shoot fresh weight compared with the unsprayed control were calculated and analysed. Regression curves were fitted to mean values using Minitab statistical package, Version 9.2. Chlorsulfuron rates giving 50% reduction in shoot fresh weight (GR_{50}) were calculated for each line from the regression equations.

RESULTS AND DISCUSSION

Chlorsulfuron rates were chosen according to sensitivity of different lines following preliminary experiments (Conner *et al.*, 1994). Wild type Brassica plants showed 56% reduction in dry weight and 77% reduction in fresh weight with chlorsulfuron application as low as 1 g a.i./ha (Figure 1). Both mutagenized lines showed increased resistance to chlorsulfuron compared with the parent wild type. Some symptoms of herbicide injury were observed on these plants. The symptoms included stunting, loss of apical dominance, anthocyanin pigmentation, chlorosis and leaf abscission and were more severe at higher chlorsulfuron rates. Line 19c was relatively resistant and its fresh weight was reduced by 43% when sprayed with 10 g a.i./ha chlorsulfuron, a rate close to the recommended field dose. At the highest rate of chlorsulfuron (90 g a.i./ha), line 19c showed 80% reduction in fresh weight. Line 30a was the most resistant with only 5% and 36% reductions in fresh weight with chlorsulfuron applications of 10 and 90 g a.i./ha, respectively (Figure 1).

GR_{50} values based on reduction in fresh weights were estimated as 0.3, 14.4 and 109.1 g a.i./ha for wild type, 19c and 30a, respectively. Therefore, lines 19c and 30a showed 48 and 363 times more resistance to chlorsulfuron than the parent wild type. Magha *et al.* (1993) reported that a mutant line of *B. napus* was 250-500 times more tolerant to chlorsulfuron than the sensitive control in seedling bioassays, but did not tolerate the field rates recommended for cereals.

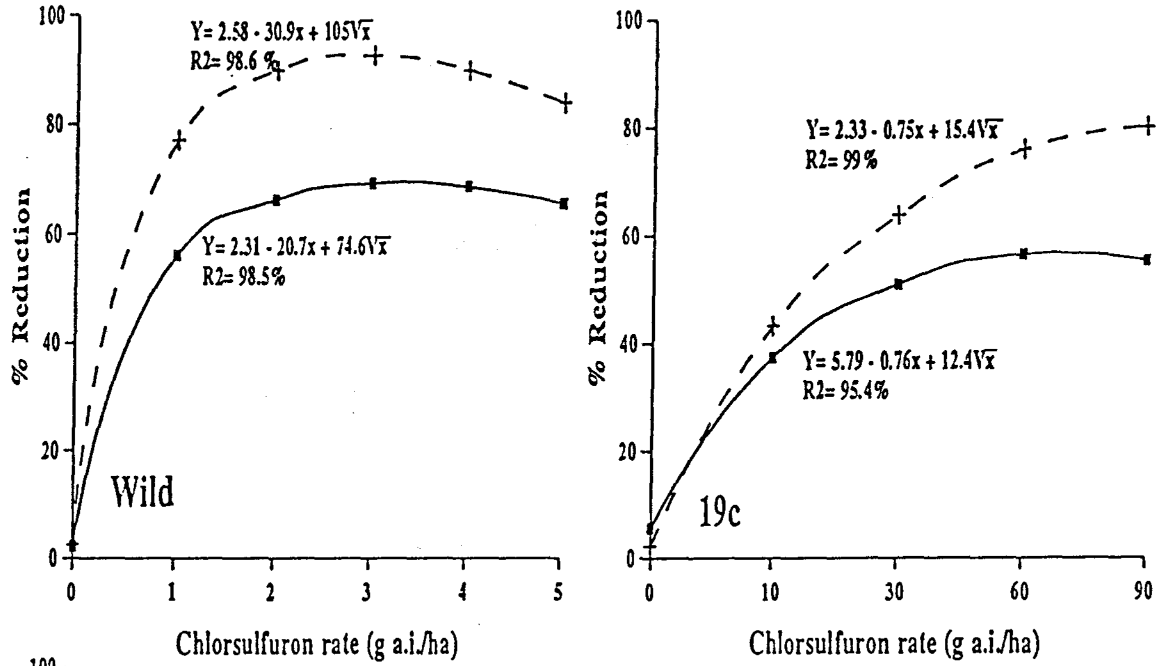
Resistance to ALS inhibiting herbicides has been related to three possible mechanisms. Firstly, the general tolerance to sulfonylurea and imidazolinones by crop plants appears to be due to rapid metabolism to non-toxic products (Sweetser *et al.*, 1982; Ladner, 1991). Moreover, differences in chlorsulfuron tolerance between wheat cultivars were related to their rate of metabolism of the herbicide (Dastgheib and Field, 1995). Secondly, differences in ALS levels in the roots of maize inbred lines were shown to explain their differential sensitivity to chlorsulfuron (Forlani *et al.*, 1991). Thirdly, an altered form of ALS with less sensitivity to inhibotors was reported to be the main reason for development of resistance in several weed species (Saari *et al.*, 1992) and in mutagenized or selected lines of crop plants (Hart *et al.*, 1992; Magha *et al.*, 1993). Our previous report on the Brassica lines provided evidence that the resistance to chlorsulfuron by the lines 19c and 30a was conferred by a single dominant mutation (Conner *et al.*, 1994.) Although the possibility of other mechanisms of resistance are not discounted, it is likely that insensitivity of the target enzyme as a result of mutation is the main reason for the increased resistance of the Brassica lines to chlorsulfuron. This is consistent with another report on a chlorsulfuron resistant rapeseed isolated by protoplast culture (Magha *et al.*, 1993).

Data in Table 1 shows a reduction in shoot fresh weight of over 90% with either tribenuron or imazapyr for the wild rape line. Line 19c did not tolerate imazapyr but was moderately tolerant to tribenuron. There was a significant reduction in shoot fresh weight of this line when sprayed with tribenuron, but this amounted to 30% only. Line 30a was highly sensitive to imazapyr but showed resistance to tribenuron with no significant reduction in shoot fresh weight when sprayed with this herbicide.

Table 1: Shoot fresh weight (g) of Brassica lines 21 days after spraying with ALS inhibiting herbicides

	Herbicide treatment		
Line	**0**	**tribenuron**	**imazapyr**
Wild	18.6 (1.4)[1]	1.7 (0.4)	1.7 (0.2)
19c	17.2 (1.0)	11.9 (0.9)	1.5 (0.2)
30a	16.3 (1.3)	15.9 (2.5)	1.4 (0.3)

1. Values in brackets are standard error of the mean.



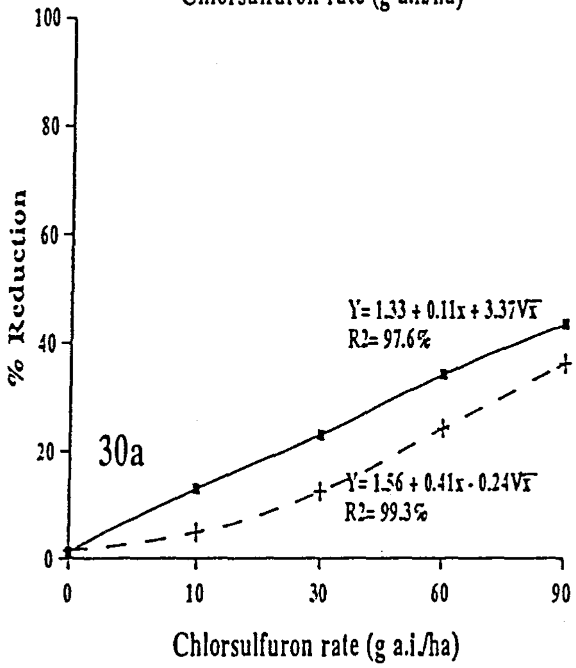


Figure 1: Dose response curves for reductions in fresh weight (+) and dry weight (■) of Brassica lines at different chlorsulfuron rates.

Line 30a was originally selected for resistance to chlorsulfuron and showed cross resistance to tribenuron, another sulfonylurea compound, but not to imazapyr, an imidazolinone herbicide. Although both groups of herbicides inhibit ALS enzyme, there is enough evidence to suggest that their binding sites may be different (Saxena and King, 1990; Vaughn and Duke, 1991). This may explain the lack of cross resistance of line 30a to imazapyr. Further work is currently underway to advance the understanding of the basis of resistance in Brassica lines to different classes of ALS inhibitors.

REFERENCES

1. Beyer E.M., M.D. Duffey, J.V. Hay, D.D. Schlueter. 1988. Sulfonylureas. *in*: Kerney P.C., D.D. Kaufman (eds.). Herbicides: Chemistry, Degradation and Mode of Action. Vol. 3. p117-189. Mercel Dekker Inc. USA.
2. Conner A.J., D.J. Abernethy, F. Dastgheib, R.J. Field. 1994. *Brassica napus* mutants with increased chlorsulfuron resistance. *Proceedings 47th N.Z. Plant Protection Conference.* p173-177.
3. Dastgheib F., R.J. Field 1995. Calculating chlorsulfuron concentration in plants: An approach for detecting the mechanism of herbicide sensitivity. *Proceedings 15th Asian Pacific Weed Science Society Conference.*
4. Field R.J., A.J. Conner, M.H. Foreman. 1993. The impact of developing herbicide resistant crop plants. *Proceedings 10th Australian Weeds Conference and 14th Asian Pacific Weed Science Society Conference.* p315-318.
5. Forlani G., E. Neilsen, P. Landi, R. Tuberosa. 1991. Chlorsulfuron tolerance and acetolactate synthase activity in corn (*Zea mays* L.) inbred lines. *Weed Science.* 39: 553-557.
6. Hart S.E., J.W. Saunders, D. Penner. 1992. Chlorsulfuron-resistant sugarbeet: Cross-resistance and physiological basis of resistance. *Weed Science.* 40: 378-383.
7. Magha M.I., P. Guerche, M. Bregeon, M. Renard, M. Issaka-Magha. 1993. Characterization of a spontaneous rapeseed mutant tolerant to sulfonylurea and imidazolinone herbicides. *Plant Breeding.* 111(2): 132-141.
8. Newhouse K.E., W.A. Smith, M.A. Starrett, T.J. Schaefer, B.K. Singh. 1992. Tolerance to imidazolinone herbicides in wheat. *Plant Physiology.* 100: 882-886.
9. Ray T.B. 1984. Site of action of chlorsulfuron, inhibition of valine and isoleucine biosynthesis in plants. *Plant Physiology.* 75: 827-831.
10. Saari L.L., J.C. Cotterman, W.F. Smith, M.M. Primiani. 1992. Sulfonylurea herbicide resistance in common chickweed, perennial ryegrass, and Russian thistle. *Pesticide Biochemistry and Physiology.* 42: 110-118.
11. Saxena P.K., J. King. 1990. Lack of cross-resistance of imidazolinone-resistant cell lines of *Datura innoxia* P. Mill. to chlorsulfuron. Evidence of separable sites of action on the target enzyme. *Plant Physiology.* 94: 1111-1115.
12. Stidham M.A. 1991. Herbicides that inhibit acetohydroxyacid synthase. *Weed Science.* 39: 428-434.
13. Sweetser P.B., G.S. Schow, J.M. Hutchison. 1982. Metabolism of chlorsulfuron by plants: biological basis for selectivity of a new herbicide for cereals. *Pesticide Biochemistry and Physiology.* 17: 18-23.
14. Vaughn K.C., S.O. Duke. 1991. Biochemical basis of herbicide resistance. *in:* Ebing W. (ed.). Herbicide Resistance - Brassinosteroids, Gibberellins, Plant Growth Regulators. Chemistry of Plant Protection 7. p141-169, Springer-Verlag, Germany.

CHARACTERS OF SEED EMERGENCE AND EFFECT OF SULFONYLUREA RICE HERBICIDES ON THREE BIDENS PADDY WEEDS

Itoh, K., J. J. Lee*, T. Sumiyoshi** and M. Tachibana
Tohoku Natl. Agric. Expt. Stn., Omagari, Akita 014-01 Japan

Abstract

Bidens tripartita, a native species, is a serious paddy weed in Northern Japan and Korea. B. radiata var. pinatifida were found in paddy fields of small mountain areas in Iwate and Miyagi Pref., Japan and Chungchong Nam and Puk Province, Korea. B. frondosa, an introduced plant from North America has become a troublesome weed of paddy and aquatic ecosystems in all rice producing areas of the two countries.

These seeds are able to germinate after one to two months in storage under wet soil conditions. It is very difficult for a germinated plant to establish when submerged in water, however, if a plant is submerged just after emergence, most can establish easily. Different effects of some sulfonylurea rice herbicides on the Bidens weeds are discussed.

Key words; Bidens paddy weeds, sulfonylurea rice herbicides, Bidens tripartita, Bidens frondosa

Present address *; Honam Crop Expt. Stn., Iri 570-080 Korea, **; Kyusyu Natl. Agric. Expt. Stn., Chikugo, Fukuoka 933 Japan

Introduction

Trifid Bur Marigold, Bidens tripartita L., a native species, is a serious paddy weed in Northern Japan and Korea now[1]. B. radiata Thuill. var. pinati fida Kitam. were found only wet land in Hokkaido and Tohoku, Japan and Chungchong Nam and Puk Province, Korea. Beggar Ticks, B. frondosa, an introduced plant since 1910's from North America has become a troublesome and noxious weed of paddy and aquatic ecosystems in all rice producing areas of the two countries after World War 2[3,4].

Bensulfuronmethyl(BSM), Pyrazosulfuronethyl(PSE) and Imazosurufuron(ISF) belonging to sulfonylurea class are broad spectram herbicides that control most annual and perennial broadleaf weeds and sedges in lowland rice in Japan and Korea

Materials and Methods

Surveys on Bidens weeds in paddy fields were conducted from July to Novem ber in 1993 in a transect of Honsyu Island from Japanese sea side to Pacific sea side of Tohoku area and most of rice producing zones of Korea.

Experiment 1: Seed dormancy test

Materials: Seeds of B. tripartita and B. frondosa are collected from our experimantal fields in Omagari, Akita. Seeds of B. radiata var. pinatifida are collected from terrace rice fields in Iwate Prefecture in the autumn 1993.

Methods: Artificially buried in the wet soil and submerged for stratification. The seeds of 3 species were stored in the soil inside of green house, inside of 5° C controled incubator and out door conditions. One, 2 and 3 monthes after the seeds were recovered, Petri dish with wet filter paper experiments were condcted ambient temperature 25° C (day time; 12hr., 5,000 lx), 15 ° C (night time; 12hr.) in a incubator. Treatments were replicated four times.

Experiment 2 :A pot trial was condacted out door condition without rain in the normal cropping season from middle May to late June. Eighty seeds of dormancy broken per pot were sown on the soil surfece. Four days keep the wet conditon, and after emerged the most of seedlings, irrigation water was surprised 3 to 4 cm depth. Sulfonylurea herbicides, Bensulfuronmethyl(BSM), Pyrazosulfuronethyl (PSE) and Imazosurufuron(ISF) were tested (Table 1). Treatments were replicated four times and pots were arranged in a randomised block design after treatment.

Table 1 Herbicides and treatment time

herbicide	type	concentration	application time
Pyrazosulfuronethyl(PSE)	granule	21g a.i./ha	①、②、③
Bensulfuronmethyl(BSM)	granule	90g a.i./ha	①、②、③
Imazosurufuron(ISF)	granule	90g a.i./ha	①、②、③

①:Treatment just after emerged, 5 days after seeding (DAS, 16, May), ②:9 DAS, ③:14 DAS.

Results

<u>B. tripartita</u>, a native species, is a serious paddy weed in Northern Japan. <u>B</u>. <u>radiata</u> var. <u>pinatifida</u> were found in paddy fields of Towa-cyo in a small mountain area in Iwate and Kesennuma-city in Miyagi Pref., Japan. <u>B</u>. <u>frondosa</u>, an introduced plant from North America has become a troublesome weed in paddy fields (Fig 1).

Fig. 2. shows a differentation of <u>Bidens</u> 4 species in Korea. <u>B</u>. <u>tripartita</u> is a popular species in Korea. <u>B</u>. <u>radiata</u> var. <u>pinatifida</u> were found in paddy fields of Kyonggi, Chungchong Nam and Chungchong Puk Province, Korea. <u>B</u>. <u>frondosa</u>, an introduced plant from North America has also become a troublesome weed of paddy and aquatic ecosystems in all rice producing areas.

Broken of seed dormancy of <u>B. tripartita</u> was not effect that the 3 temperature conditions and the 2 soil water conditions to strage over two months.

Broken of seed dormancy of <u>B</u>. <u>frondosa</u> was only kept over 3 months, 5° C constant and submerged soil condition (Table 2-5). Seed dormancy of <u>B</u>. <u>radiata</u> var. <u>pinatifida</u> was shallower than the other two species (Table 3 and 5).

Table 2. Percentage of germination of Bidens 3 species after stratification of out door condition (One month after tested)

Term \ species / soil	B. tripartita Submerged	B. tripartita Wet	B. frondosa Submerged	B. frondosa Wet	B. radiata var. pinatifida Submerged	B. radiata var. pinatifida Wet
No stratification	32.8		2.8		82.1	
One month	93.3	80.3	49.5	2.0	93.7	98.1
Two months	99.3	99.5	42.0	25.0	4.0	100.0
Three months	92.5	98.2	4.0	-	1.5	99.0

Table 3. Percentage of germination of Bidens tripartita and B. frondosa after conditionings in refrigerator (5° C constant) and inside a glass house (One month after tested)

Term \ species / place / soil	B. tripartita 5 ° C Submerged	B. tripartita 5 ° C Wet	B. tripartita Glass house Submerged	B. tripartita Glass house Wet	B. frondosa 5° C Submerged	B. frondosa 5° C Wet	B. frondosa Glass house Submerged	B. frondosa Glass house Wet
No stratification	32.8				2.8			
One month	97.3	83.8	94.5	93.8	37.9	2.2	51.9	9.7
Two months	98.8	97.5	98.3	98.0	31.3	14.3	42.3	0.3
Three months	99.3	99.8	79.8	93.2	73.3	47.8	18.0	0.3

Table 4. Percentage of germination of Bidens 3 species after stratification of out door condition (Ten days after tested)

Term \ species / soil	B. tripartita Submerged	B. tripartita Wet	B. frondosa Submerged	B. frondosa Wet	B. radiata var. pinatifida Submerged	B. radiata var. pinatifida Wet
No stratification	0.0		0.0		18.4	
One month	70.9	18.5	36.8	1.3	92.2	97.7
Two months	97.5	96.4	30.0	2.0	1.0	97.5
Three months	90.0	96.8	1.0	-	0.0	97.5

Dormancy brouken seeds of 2 Bidens specise were used for herbicide pot test. After puddling, Eighty seeds per pot were sown on the soil surface, 4 days after seeding about 70 % of seedlings were emerged. After flooded of 3 cm, first aplications of 60 mg SU herbicides per pot were done at cotyledon leaf stage.

Effects of SU herbicides are not so strong aginst Bidens paddy weeds. Only BSM at 5 and 9 days after seeding (DAS) and PSE at 9 DAS for B. frondosa and PSE at 9 and 14 DAS for B. tripartita are effective. Effective plots were controled not only plant biomass but also root length (Table 6 and 7).

Table 5. Percentage of germination of Bidens tripartita and B. frondosa after conditionings in refrigerator (5° C constant) and inside a glass house condition (Ten days after tested)

species / place / soil / Term	B. tripartita 5 ° C Submerged	Wet	Glass house Submerged	Wet	B. frondosa 5° C Submerged	Wet	Glass house Submerged	Wet
No stratification	0.0				0.0			
One month	67.2	17.3	68.5	45.4	14.6	1.0	40.5	2.6
Two months	92.1	80.4	94.6	64.4	13.5	0.8	36.5	0.3
Three months	99.0	96.0	74.8	48.0	72.5	29.5	6.5	0.0

Discussion

Over wintered under submerged water condition is a broken of seed dormancy of B. frondosa. Harada et al. concluded that conditioning of B. frondosa seeds at 0° C needed over 80 days for stratification[2]. A concentration of 10 to 100 ppm of Cotylenin E. was good for germination of B. frondosa seeds[2].

The case of B. tripartita, ambient temperature and soil humidity is not so big conditions. The deepest dormancy species is B. frondosa, the shallowest species is B. radiata var. pinatifida.

PSE, a low input herbicide, is better effect for Bidens paddy weeds. In Japan and Korea, most of post emerged paddy herbicides mixed SU with Thiobencarb, Mefenacet, Pretilachlor, Pyributicarb, Butachlor and Dimepiperate. The effectless of SU is not so big problem. Further study needs the action of SU herbicide for Bidens paddy weeds.

Acknowledgements

We wish to express Dr. Y.D. Rho, Kyung-Hee University for collecting samples in Korea.

References

1) Doi,Y. and H. Morita (1978) A historical study on lowland weeds in Hokkaido. Misc. Pub. Hokkaido Natl. Agric. Exp. Stn. 14, 1-15. (Japanese with English summary)

2) Harada, J., T. Tanaka and T.Sasa (1982) Some prospects of germination and breaking dormancy by plant growth regulators against Bidens frondosa. (Japanese)

3) Kagiya, T. (1992) Ecology and control of Bidens frondosa L. Syokucyo, 26;23-27.(Japanese)

4) Kawano, S. (1975) The productive and reproductive biology of flowering plants 2. The concept of life history strategy in plants. J. Coll. Lib. Arts, Toyama Univ. 8, 51-86.

Table 6. Effects of sulfonylurea rice herbicides to <u>Bidens</u> <u>tripartita</u> (37 days after seeding)

		No. of Plants	Root* Length (cm)	Plant* Hight (cm)	Top Dry Wt. (mg)	Roots Dry Wt. (mg)	Percentage of untreated				
							No. of Plants	Root Length	Plant Hight	Top Dry Wt.	Roots Dry Wt.
PSE	①	39.3	8	6.5	192	54	76	30	73	18	8
	②	7.0	1	3.0	9	0	14	4	34	1	0
	③	17.7	4	3.7	51	7	34	15	42	5	1
BSM	①	45.7	12	9.4	723	193	88	44	106	67	30
	②	43.3	9	9.7	1215	263	84	33	109	113	41
	③	50.3	14	8.8	1422	356	97	52	99	132	55
ISF	①	50.0	24	10.2	1515	972	97	89	115	141	150
	②	52.0	21	9.6	1486	843	101	78	108	138	130
	③	51.3	23	8.8	1557	873	99	85	99	145	135
CONT.		51.7	27	8.9	1075	648	100	100	100	100	100

*:Mean of three larger plants of each 3 pots. 1 ①～③:see Table 1.
PSE;Pyrazosulfuronethyl, BSM;Bensulfuronmethyl, ISF;Imazosulfuron

Table 7. Effects of sulfonylurea rice herbicides to <u>Bidens</u> <u>frondosa</u> (37 days after seeding)

		No. of Plants	Root* Length (cm)	Plant* Hight (cm)	Top Dry Wt. (mg)	Roots Dry Wt. (mg)	Percentage of untreated				
							No. of Plants	Root Length	Plant Hight	Top Dry Wt.	Roots Dry Wt.
PSE	①	59.3	21	13.3	1186	422	92	75	73	29	29
	②	46.0	10	4.0	196	74	72	36	22	5	5
	③	46.3	13	8.0	612	326	72	46	44	15	23
BSM	①	43.3	5	5.4	157	37	67	18	30	4	3
	②	49.0	12	5.4	228	53	76	43	30	6	4
	③	58.7	12	8.9	616	158	91	43	49	15	11
ISF	①	51.3	16	17.5	1644	598	80	57	96	40	42
	②	63.7	21	15.4	2605	1035	99	75	85	63	72
	③	60.3	20	14.4	1832	583	94	71	79	44	41
CONT.		64.3	28	18.2	4120	1439	100	100	100	100	100

*:Mean of three larger plants of each 3 pots.

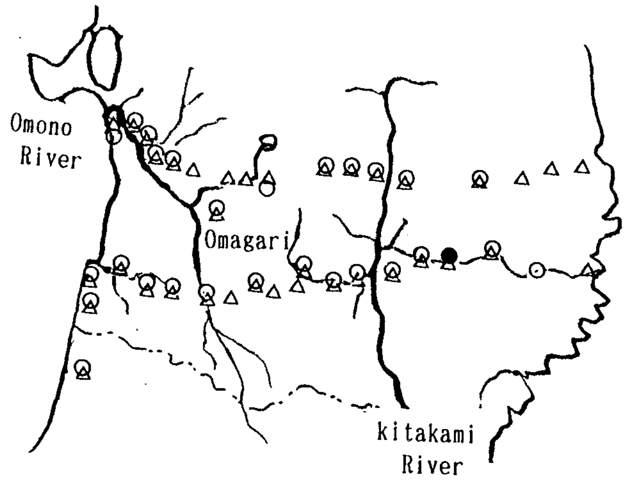


Fig. 1. Two belt transects of Honsyu Island from Japanese sea side to Pacific sea side of Tohoku area (1993)
○ :*B. tripartita*, △ :*B. frondosa*, ● :*B. radiata* var. *pinatifida*

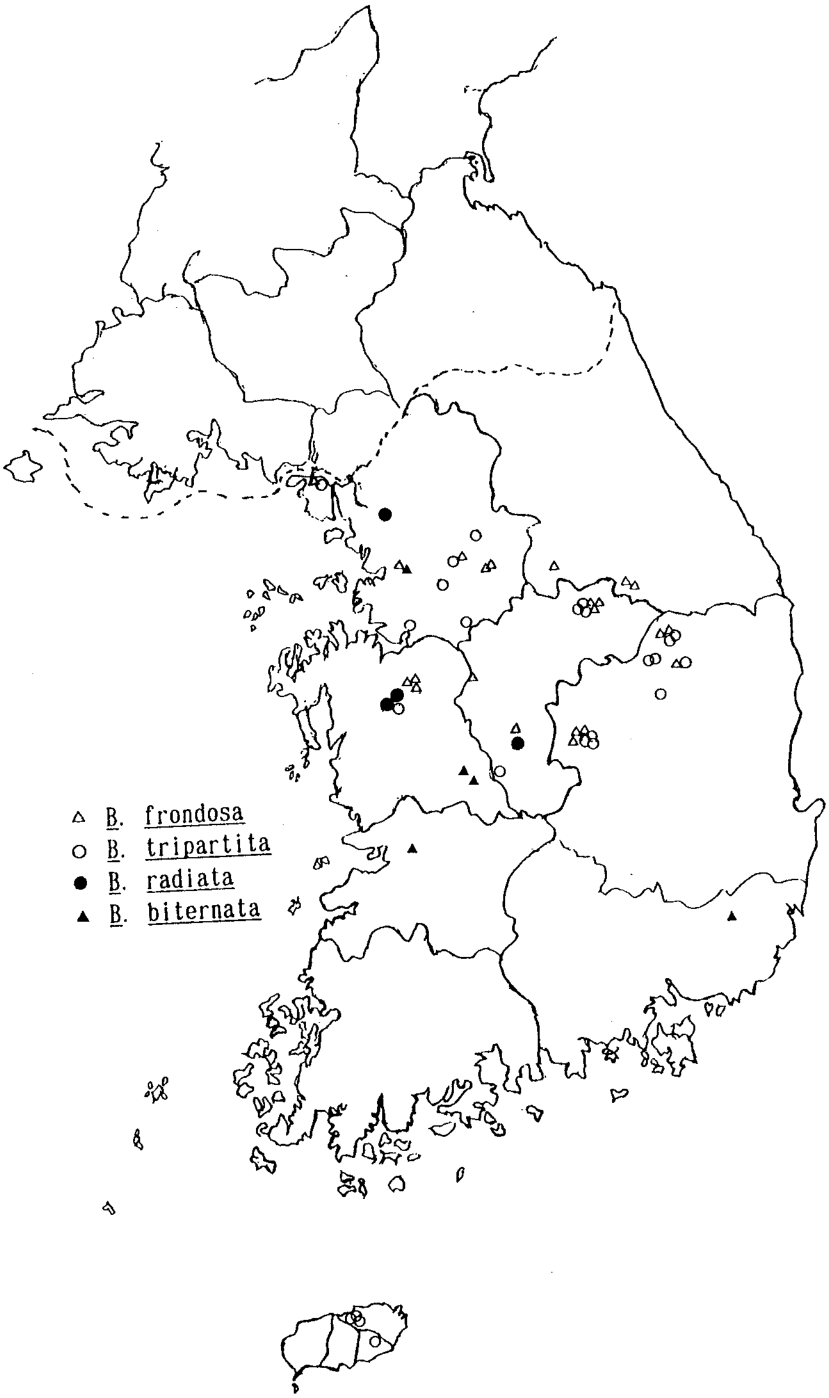


Fig. 2. A differentation of Bidens 4 species in Korea (1993)

COMBINATION EFFECT OF ANILOFOS AND 2,4-D EE IN LOW LAND TRANSPLANTED RICE - BIOEFFICACY, YIELD, RESIDUE AND ECONOMICS

S.A.RAM AND T.V.RAMACHANDRA PRASAD

Product Development Mangager, Gharda Chemicals Ltd., No.48, Hill Road, Bhandra (West), Bombay 400 050 and Agronomist (Weed control), University of Agricultural Sciences, Hebbal campus, Bangalore 560 024, INDIA respectively.

ABSTRACT

Field trials were conducted during 1992-94 in different centres (16) in India to know the performance of ready mix of anilofos and 2,4-D EE in weed control and yield of transplanted rice in relation to other herbicides. The dominant weed flora were _Echinochloa_ _oryzoides_ L., _Cyperus_ _iria_ L., _Scirpus_ sp., _Rotala_ _verticillaris_ L. and _Ammania_ _baccifera_ L. Of the various doses and combinations, anilofos 0.3 kg a.i./ha + 2,4-D EE 0.4 kg a.i./ha 5 - 7 days after planting gave yields and weed control efficiency comparable to hand weeding twice at all the centres. The ready mix enhanced the weed control spectrum by lowering sedges and broadleaf weeds. Other good herbicides were pretilachlor 0.5 kg. a.i./ha, butachlor 1.5 kg a.i./ha, butachlor 1.0 kg a.i./ha + 2,4-D EE 0.4 kg a.i./ha and anilofos 0.4 kg a.i./ha + 2,4-D EE 0.53 kg a.i./ha (all 5 - 7 DAP). The herbicides were cheaper than the labour required for hand weeding. Half lives of anilofos and 2,4-D EE alone or in combination were 9 and 25 days respectively. The contents of herbicide were below permissible limit in soil, grain and straw of rice at harvest.

Key words : Anilofos, 2,4-D EE, Ready mix, Bioefficacy, Herbicide residue, Half life.

INTRODUCTION

Rice (_Oryza_ _sativa_ L.) is grown in India under varied systems - puddled lowland, upland, drilled and tansplanted conditions with different ecological situations favouring varied weed flora. Weed problem gets lowered due to transplantation as compared to drilled and upland rice. Even a conservative estimate of 15 % yield loss in field crops due to weeds will cost around $ 30 millions in India annually (Mukhopadhyay, 1992). Effective control of weeds can be attempted by using herbicides like pendimethalin 2.0 kg a.i./ha, butachlor 1.0 - 1.25 kg a.i./ha, oxadiazon 0.5 kg a.i./ha, anilofos 0.4 kg/ha, 2,4-D EE

0.8 kg/ha (Consolidated Technical Report, 1984; AICRPWC, 1986). Continuous use of these herbicides have lead to narrow spectrum of weed control (DeDatta and Herdt, 1981). Anilofos is very effective on grasses only. In order to have broad spectrum of weed control, combinations of herbicides and integrated methods have done excellent work in controlling weeds in rice (De Datta and Hert, 1981; Ali and Sankaran, 1985; Avudaithai et al., 1993; AICIRIP, 1994). In this direction, bioefficacy of anilofos + 2,4-D EE (ready mix) was evaluated for broad spectrum of weed control in lowland rice at different places in India.

MATERIAL AND METHODS

Field studies were conducted during wet and winter seasons of 1992 - 94 in sixteen agro-ecological conditions - Karnataka, Kerala, Andha Pradash, Maharastra, Orissa, Tamil Nadu and West Bengal states. These trials were conducted under Agricultural Universities at Bangalore, Rajendranagar, Coimbatore and Centres of Rice Directorate, Rajendranagar, Hyderabad, India. The experimental sites were sandy clay loam to clay loam with average fertility status (available nutrients 300 to 400 kg N, 12 to 22 kg P and 315 to 410 kg K per ha) and soil pH of 6.5 to 7.5. Nine weed control treatments (see Table 1 for details) were compared in a RBD with 3 replications. The pre-emergent herbicides (5 - 7 days after planting, DAP) tested were 2,4-D EE (36 % EC), anilofos (anilogaurd 30 % EC), butachlor (machete 50 % EC and pretilachlor (Rifit 50 % EC). Ready mix herbicide of M/S Gharda Chemicals Ltd., Bombay was Anilogaurd plus which contains anilofos (24% EC) and 2,4-D EE (32 % EC). Crops were raised following recommended fertilizer schedules for each location. Two quadrats of 0.25 sq.m were placed randomly at four places in each plot and weed count species wise was made periodically. Weed dry matter was worked out at 30 DAP and harvest. Weed control efficiency was estimated based on weed count. Economics based on the cost of labour and herbicides were worked out and presented.

The degradation pattern of 2,4-D EE at 0.4 kg/ha, anilofos at 0.3 kg/ha and anilofos 0.3 kg/ha + 2,4-D EE 0.4 kg/ha was studied by collecting soil samples (0 - 15 cm soil layer) at 0,5,10,15,30,45,60 & 90 days after application and at harvest. The herbicide content was estimated using the following procedure.

The anilofos was extracted with acetone and the cleanup was accompanied with sodium chloride. The determination was done with the help of HPLC equipped with UV visible detector with the following working conditions (column: Inertsil ODS 2; Mobile phase: HPLC methanol 100 %; Flow rate: 1 ml/min.; wave length 230 nm; retention time: 1.86 min.(Jayakumar and Sree Ramulu, 1993). The 2,4-D was extracted with solvent mixture consisting of acetonitrile, water and glacial acetic acid (8:2:1) and subjected to vacuum filtration. Cleanup was accompanied by partition with sodium carbonate and hexane extraction. The concentrated hexane was used for GC determination (Detector: Electron capture detector, Column: 2% DC 200, temperature conditions °C; column 200, injector 210, detector 240; flow rate 1 ml/min, retention time 110 sec (Jayakumar, 1991; Jayakumar and Sree Ramulu, 1993).

At harvest, the content of the herbicides was estimated in grain and straw of rice.

RESULTS AND DISCUSSION

The major weed flora of the experimental fields were Cyperus iria L., C difformis L., Scirpus sp. Fimbristylis miliacea (among sedges), Echinochloa oryzoides L., E.glabrescens, Panicum tripheron (among grasses), Rotala verticillaris L., Ammania baccifera and Monochoria vaginalis (among broadleaf). All the herbicides were not effective on sedges particulary Scirpus sp, while they except 2,4-D EE gave very good control of grasses. Anilofos and pretilachlor were not effective on broadleaf particularly R.verticillaris. Inclusion of 2,4-D EE along with anilofos increased the spectrum of activity by controlling effectively broadleaf weed (Table 1). Most of the herbicides were effective in lowering weed dry matter due to good weed control efficiency (>70 %). The ready mix of anilofos + 2,4-D EE was comparable to butachlor and pretilachlor with regards to weed control (Table 1). This pattern has been observed by Jayakumar (1991) and Avudaithai et al. (1993).

In all most all places, application of anilofos 0.3 kg +2,4-D EE 0.4 kg/ha , anilofos 0.4 kg + 2,4-DEE 0.53 kg/ha and butachlor 1.0 kg + 2,4-D EE 0.4 kg/ha gave grain yield comparable to two hand weedings. This was reflected by good control by these herbicides. Further, anilofos, 2,4-D EE and butachlor alone gave grain yield lower than hand weeding as a result of limited spectrum of weed control (Table 1). Weed competition lowered grain yield by 32 to 51 % as compared to hand weeding (1992 - 94) owing to reduced panicles m^{-2}. Similarly Avudaithai et al. (1993) and Jayakumar et al. (1994) observed that higher yields in plots treatmented with anilofos + 2,4-D EE as compared to anilofos or 2,4-D EE alone mainly due to limited weed control spectrum (Ranganayaki,1990).

The degradation pattern of 2,4-D EE and anilofos in the soil followed first order equation. 2,4-D EE 0.4 kg/ha alone or with anilofos showed a very low quantity at harvest. While anilofos at 0.3 kg/ha alone or in combination with 2,4-D EE showed non detectable limit at harvest (Fig. 1) (Jayakumar and Sree Ramulu, 1993).

The half life of anilofos at 0.3 kg/ha was 11 to 13 days when tried alone, while it ranged from 9 to 13 days when mixed with 2,4-D EE. The half life for 2,4-D EE at 0.4 kg/ha ranged from 18 to 25 days when tried alone and 17 to 24 days when mixed with anilofos (Jayakumar and Sree Ramulu, 1993).

With regards to herbicide content in plant, very low dose of anilofos and 2,4-D EE was observed in the grain, while in the straw, the doses of anilofos and 2,4-D EE were sligthly higher at harvest (Table 3). The herbicide content was observed to a lesser extent in anilofos at 0.4 kg/ha and 2,4-D EE 0.8 kg/ha. However, the contents of anilofos and 2,4-D EE were below detectable limit in the herbicide application of anilofos 0.3 kg/ha +2,4-D EE 0.4 kg/ha (Jayakumar, 1991; Jayakumar and Sree Ramulu, 1993).

Based on the rice yield of 1994, the economics of weed control treatments was worked out (Table 2). Among the herbicides, marginal returns (over control) were higher in 2,4-D EE + anilofos at both the doses and compared well with hand weedings. The next best were anilofos 0.4 kg/ha and butachlor 1.5 kg/ha. Considering the returns (MR) and cost of weed management (MC), the benefit cost ratio (MR/MC) was much higher in herbicide applied treatments as compard to hand weeded plot. Based on the field bioefficacy, returns and cost of weed management, anilofos 0.3 kg + 2,4-D 0.4 kg/ha showed superiority to the herbicides applied alone. This could be explained by increased spectrum of weed control due to mixtures of herbicides as stated by Jayakumar (1991) and Jayakumar et al. (1994).

Based on the several locations, it can be inferred that anilofos 0.3 kg + 2,4-D EE 0.4 kg/ha showed good in weed control, higher yield, better returns and lowest detectable herbicide content in soil and plant systems. Herbicides alone had narrow spectrum of weed control.

ACKNOWLEDGMENTS

The studies in Agricultural Universities was sponsored by M/S Gardha Chemicals Ltd., Bombay. The data of trials laid out by Rice Directorate, Rajendranagar have been used here. The senior author is thankful to the Institutions for conducting the trails.

REFERENCES

AICRIP, 1994. All India Coordinated Rice Improvement programme. Progress report for kharif 1994, Hyderabad, India.

AICRP WC 1986. All India Coordinated Research Programme on Weed Control. Annual progress report - Coimbatore, Tamil Nadu Agricultural University, Coimbatore, India. pp 10-20.

Ali, A.M. and S.Sankaran, 1985. Effect of pre-emergence herbicides on Echinochloa crus-galli (L. Beauv) and Cyperus difformis L. in transplanted rice. IRRN , 10(2): 20.

Avudaithai,S., S.Sankaran and R.Jayakumar. 1993. Efficacy of anilogaurd plus in transplanted rice. Pestology 17(3): 42-45.

Consolidated Technical Report. 1984. All India Coordinated Research Programme on Weed Control, Bangalore centre, 1978 to 1984, University of Agricultural Sciences, Bangalore. pp 144.

De Datta, S.K. and R.W.Herdt. 1981. Weed control technology in irrigated rice. p 89-108. In. Proceedings of the Conference on Weed Control in Rice. Aug. 31 to sept 14, 1981. International Rice Research Institute, Manila, Philippines.

JayaKumar,R. 1991 Dynamics of anilofos and 2,4-D EE in soils and their bioefficacy in rice. Ph.D. Thesis. Tamil Nadu Agricultural University, Coimbatore, India. pp 22-158.

Jayakumar,R. and U.S.Sree Ramulu. 1993. Degradation and persistence of herbicides in transplanted rice. Proc. Int. Symp.Indian Soc. Weed Science, Hisar, India. Nov.18-20, 1993. Vol II, pp 101 - 105.

Jayakumar,R.,P.Nalayini and S.Sankaran. 1994. Bioefficacy of Anilofos 50 EC in transplanted rice. Pestology, 18(8): 29-35.

Mukhopadyay,S.K. 1992. Emerging problems and advances in weed management. Presidential address of the section of Agricultural Sciences of the 79th session of Indian Science Congress, 1992, India.pp 1-16.

Ranganayaki, S. 1990. Efficacy of anilofos and 2,4-DEE on lowland rice ecosystems. M.Sc.(Ag.) Thesis, Agronomy Dept. Tamil Nadu Agricultural University, Coimbatore, India. pp 26-80.

Table 1. Efficacy of herbicides on weed control, yield and yield parameters of transplanted rice, 1992-94, different locations, India, winter and wet seasons.

	Herbicides	Dosage (kg ai/ha)	Grain yield (t/ha) 1992(4)*	94(16)	Panicles per m^2	Weed dry matter g/m^2 -Harvest	Weed control efficiency (%, 30 DAP) Sedge	Grass	B.leaf
1.	2,4-D EE	0.8	-	4.35	208	73.0 (76.4)**	32	49	78
2.	Anilofos	0.4	3.91	4.56	214	96.5 (68.9)	28	78	33
3.	Anilofos + 2,4-D EE	0.3 + 0.4	4.54	4.74	221	82.8 (73.3)	30	57	52
4.	Anilofos + 2,4-D EE	0.4 + 0.53	4.90	4.85	221	59.3 (80.9)	37	64	60
5.	Butachlor	1.5	3.94	4.64	210	66.8 (78.5)	42	76	50
6.	Butachlor + 2,4-D EE	1.0 + 0.4	4.73	4.60	208	65.5 (78.9)	-	-	-
7.	Pretilachlor	0.5	4.18	4.39	204	66.7 (78.5)	37	80	32
8.	Hand weeding (20 & 40 DAP)		4.80	4.92	226	18.8 (95.9)	83	74	65
9.	Unweeded control		2.36	3.33	146	309.7	-	-	-
	C.D. (P=0.05)		0.42	0.51	16	38.2			

* Number of locations, ** weed control efficiency (%); 1992 - winter season, 1994 - wet season B.leaf- Broad leaf

Table 2. Economics of herbicide treatments in transplanted rice, wet season 1994.

	Herbicides	Dosage (kg ai/ha)	Grain yield (t/ha)	Marginal returns (MR) US $/ha	Cost of weed control (MC) US $/ha	MR/MC
1.	2,4-D EE	0.8	4.35	102	8.4	12.1
2.	Anilofos	0.4	4.56	123	10.0	12.3
3.	Anilofos + 2,4-D EE	0.3 + 0.4	4.74	141	11.3	12.6
4.	Anilofos + 2,4-D EE	0.4 + 0.53	4.85	152	14.5	10.4
5.	Butachlor	1.5	4.64	131	15.6	8.4
6.	Butachlor + 2,4-D EE	1.0 + 0.4	4.60	127	14.4	8.8
7.	Pretilachlor	0.5	4.39	106	-	-
8.	Hand weeding (20 & 40 DAP)		4.92	159	28.1	5.7
9.	Unweeded control		3.33	-	-	-

MR = Returns over control, MC = Marginal cost, Cost of inputs, US $ - labour 0.94 / day; 2,4-D EE 3.12, Anilophos 6.25, Butachlor $ 4.69 per litre; Cost of herbicide application $ 1.56 /ha; cost of paddy 100 $ /ton.

Table 3. Herbicide content (ppm) in the grain and straw samples of rice at harvest, Coimbatore.

Treatments	Herbicide content (ppm) Grain	Straw
Anilofos 0.4 kg/ha	0.008	0.018
Anilofos 0.3 kg +	ND	ND
2,4-D EE 0.4 kg/ha	BDL	BDL
2,4-D EE 0.8 kg/ha	0.0035	0.0067

ND - Not Detectable, BDL - Below Detectable Limit.

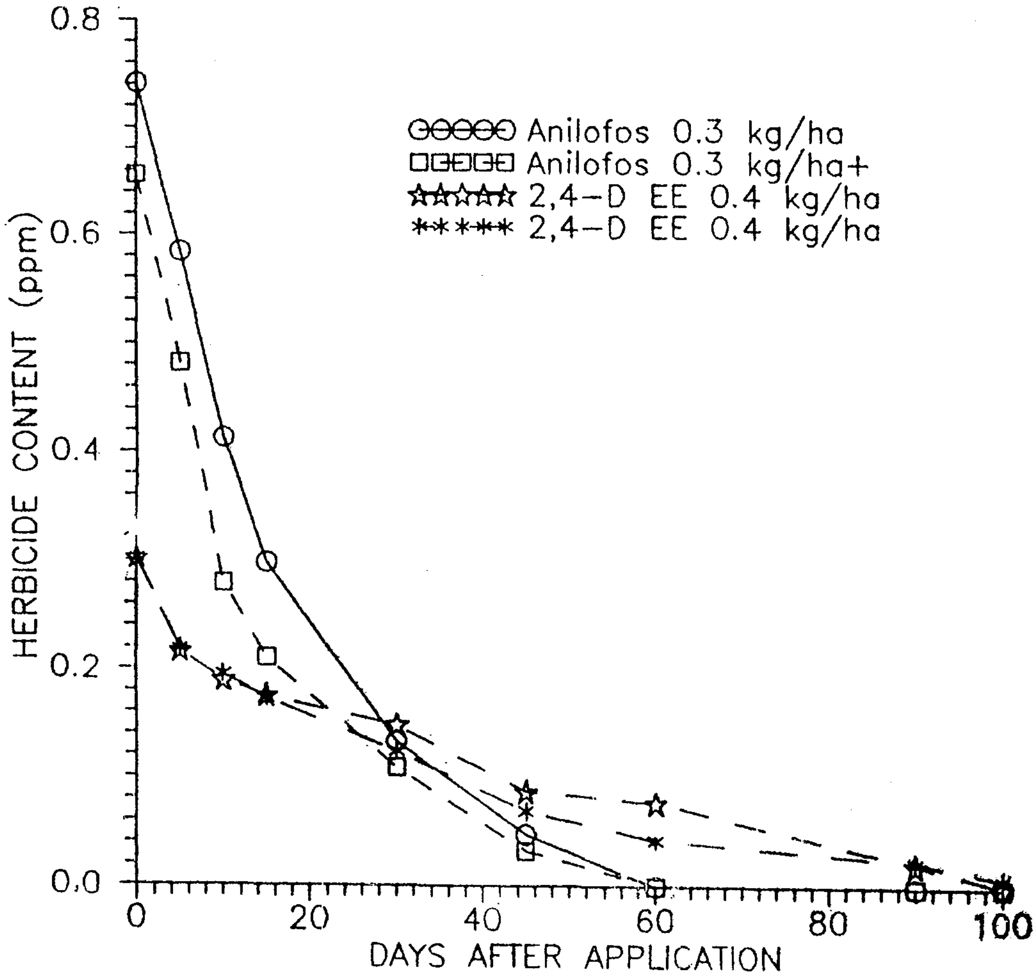


Fig.1. Degradation pattern of anilofos and 2,4-D EE in clay loam soil, Coimbatore.

GROWTH RESPONSE OF RICE AND BARNYARDGRASS SEEDLINGS TO QUINCLORAC UNDER VARIOUS GROWING CONDITIONS

S. U. Chon[1*], J. O. Guh[1], S. U. Han[1], S. L. Kwon[2], and O. D. Kwon[3]

1:Chonnam National University, Kwangju 500-757, Korea
2:BASF Korea, Seoul 100-094, Korea
3:Chonnam PRAD, Naju 523-830, Korea

Abstract : Formulated quinclorac[3, 7-dichloro-8-quinoline carboxylic acid] at 600 g a.i./ha was sprayed 10 days after seeding or transplanting of rice or barnyardgrass under various growing conditions in a greenhouse. Quinclorac inhibited plant height, root length and shoot fresh weight of rice 18, 17 and 15%, respectively, when rice was broadcast on dry soil surface. But it did not affect growth of rice under the other growing conditions. Quinclorac completely inhibited growth of barnyardgrass under all growing conditions tested. Microscopic examination of rice seedlings showed no anatomical changes by quinclorac treatment in any growing conditions. In barnyardgrass seedlings quinclorac caused inhibition of meristem elongation, and the its leaf primordia were often vacuolated, constricted and occasionally ruptured. These cellular changes of barnyardgrass by quinclorac treatment were greater under dry seeding than under water seeding condition. The results showed that quinclorac is highly safe to rice under all growing conditions, except for broadcast rice on dry soil and gave excellent bioefficacy under all growing conditions evaluated.
Key words: Quinclorac, rice, barnyardgrass, various growing conditions, microscopic examination

Introduction

Recently, rice cultivation system in Korea is changing from transplanting into direct seeding. So far, satisfactory weed control in transplanted rice was acheived by one application with one-shot herbicide, whilest sequential applications are required to acheive satisfactory weed control in direct seeded rice and foliar-applied herbicides that can be applied in late season are important in direct seeded rice. Therefore, it is essential that weed control system be reestablished in terms of phytotoxicity and efficacy of herbicides in direct seeded rice. Rice(*Oryza sativa* L.) is practically planted in many countries including Korea and is one of the most important food crops. Barnyardgrass(*Echinochloa crus-galli* spp.) is a most troublesome-gramineous weed, which is very similar to rice in the morphological characteristics and ecological requirements for water, nutrients and various meteorological factors, and this leads to high competition which resulted in great yield losses of rice(14, 15). Smith(5) reported that season-long competition of barnyardgrass at densities of 11 to 269 plants/m^2 reduced grain yields 25 to 79% in an optimum stand of rice. And Cahzone(4) suggested that each 100 kg/ha dry matter of *Echinochloa* reduced rice grain yields 42 to 72 kg/ha. One report(17) showed that growing point of drilled rice in soil was very safe to herbicides applied, but that of broadcast rice on soil surface got a great injuries due to easy exposure to herbicide. On the other hand, even though growing point of barnyardgrass was located in soil, it was exposed easily above soil surface by the enlargement of mesocotyl and was contacted to herbicide. The effects of quinclorac on cellular morphology within leaves and stems of the susceptable species are not well investigated, and thus histological examination of treated tissues can identify probable site of compound-specific activity. Bellinder et al(6) found that using histological techniques HOE-398665 caused cellular destruction(rupture) and contortion of the interveinal mesophyll cells with concomitant disorganization of the bundle sheath cells in redroot pigweed and fall panicum. Jain et al(24) showed that sethoxydim, fluazifop and haloxyfop inhibited both cell division and cell elongation in young internodes of wild oat at 5-leaf stage. Quinclorac is a herbicide applied pre-emergence and post-emergence(2, 3), and has high selectivity to paddy rice(2, 3, 8, 11). It is used to effectively control barnyardgrass in direct seeded and transplanted rice. Quinclorac is rapidly photodecomposed and has little volatility and light adsorptability in soil colloid. After application, quinclorac is absorbed through roots and leaves, and it is translocated into the meristematic regions of barnyardgrass. Guh et al(9) reported that minimum rates of application of quinclorac were 75 and 150 g ai/ha for water seeding or transplanting and for dry seeding of rice, respectively, when applied 10 days after seeding or transplanting. In a study on the tank-mix feasibility reducing the application rate of quinclorac, combination of quinclorac(150g ai/ha) with propanil(263g ai/ha) controlled 85% of barnyardgrass but with molinate(190g ai/ha) controlled 67%(1). Hong(10) et al found that damaged leaf of Iripi which is considered as a susceptible barnyardgrass showed prominent membrane disruption in the electromicroscopic study of quinclorac action. The objectives of this study were to determine the effect of quinclorac on biological characters of rice and barnyardgrass and to anatomically examine the effects of quinclorac on growth of rice and barnyardgrass seedlings under various growing conditions.

Materials and Methods

This study was conducted in greenhouse pots at Chonnam National Univerity in 1992 and 1993. Rice cultivar was "Tongjin", which is a Japonica type and a middle to late maturing cultivar. Barnyardgrass seed was collected in the field in 1991 and were kept in a refrizerator(4℃) until use. Seed of rice and barnyardgrass was planted in pots filled with paddy soil(clay loam). Under dry conditions rice was broadcast on soil surface and seeded 1cm deep in soil, and barnyardgrass was also seeded 1cm deep in soil. Under water condition, rice was seeded on soil surface and in soil, and barnyardgrass was seeded in soil. Additionally, rice seedlings at 8 days old were transplanted 2cm deep, each pot had 5 seedlings. In this study rice and barnyardgrass were grown in the separate pots to prevent them from interspecific competition. Fertilizers of N, P_2O_5, and K_2O were applied at 7, 4, and 5 kg/10a, respectively, and half the nitrogen was applied during the soil preparation. Temperatures were 28/21℃ for day/night, and light was kept at 12,000 to 20,000 lux by supplementing with artificial metal light. Formulated quinclorac at 600g a.i./ha were applied to rice and barnyardgrass grown under various growing conditions at 10 days after seeding or transplanting. At 5 and 10 days after treatment the plants of rice and barnyardgrass were harvested to determine plant weight, root length, fresh wight of above and below-ground parts, and to examine anatomical response to quinclorac. The base of stems, and middle part of the first leaf were subdivided into 8 mm long and were soaked in FAA solution to fix for 12 hours. The samples were dehydrated in a series of increasing ethanol concentrations from 30 to 100% and then were transfered in xylene/ethanol solution. They were infiltrated in paraplast solution at 60℃ for 5 days and embedded(20). The samples were rotary microtomed at 8 μm thick in cross and logitudinal sections. Following removal of wax, they were stained with safranin solution(0.5% w/w) for 1 hour in distilled water and counterstained for 12 seconds in 0.5% Fast-green FCF solution(0.5% w/v) in 95%(v/v) ethanol. Light microscope at ×100 and ×400 magnification was used to examine mesophyll cell and vascular bundle sheath cells of leaf blade, leaf primordia and leaf sheath in cross sections. In longitudinal sections, elongation of meristematic tissues and leaf primordia were examined.

Results and Discussion

1. Growth Response

At 5 days after foliar application, quinclorac inhibited the plant height of broadcast and seeded rice, and of barnyardgrass 50, 15, and 43%, respectively, under dry condtion but root length of them was not affected by quinclorac treatment. Under water contitions, quinclorac reduced plant hight of barnyardgass by 55%, but did not affect the root length of broadcast rice and barnyardgrass. No difference was observed in the plant hight and root length of transplanted rice(Fig. 1.). The study showed that quinclorac did not affect water seeded rice and transplanted rice, but inhibited growth broadcast of rice under dry conditions. Plant height of seeded rice was higher than that of broadcast rice surface under dry conditions, but there was no difference in root length of rice between seeded and broadcast rice. Under water conditions, plant height and root length of treated rice were higher than those of untreated rice. Growth of barnyardgrass seedlings was severely inhibited by quinclorac treatment under water condition. In the long run, it indicates that seeded rice was safer than broadcast to quinclorac, and that water-seeded rice was safer than dry-seeded rice to quinclorac. Rice that was broadcast on soil surface would have more possibility to contact with quinclorac. Foliar-applied quinclorac can easily control barnyardgrass regardless of growing conditions. At 10 days after quinclorac application, the plant height of broadcast rice that was broadcast on top soil was reduced by 18%, while that of seeded rice was not affected. But the root length of broadcast rice on top soil was reduced 17% by quinclorac. Barnyardgrass growth was completely inhibited. On the other hand, under water conditions, the plant height of rice regardless of seeding depth was higher than that of untreated control but quinclorac killed barnyardgrass completely(Fig. 2.). Results of this research indicated that rice seedlings treated with quinclorac were recovered at 10 days after application, except for broadcast rice. And water-seeded and transplanted rice was safer than dry-seeded rice to quinclorac. At 10 days after application, quinclorac inhibited shoot fresh weight of broadcast rice 15% and barnyardgrass 100%, respectively(Fig. 3). On the other hand, quinclorac did not affect growth of seeded and transplanted rice seedlings under water conditions like other report(18). Seaman et al(16) reported that the growth of dry seeded rice was much safer to herbicides applied, than that of water seeded rice. That shoot fresh weight of seeded rice was greater than that of broadcast rice under dry condition was probably due to deficiency of water on soil surface(19). Shybayama(21) reported that benthiocarb altered the growth and development of shoot of barnyardgrass and beared sprangletop seedings but did not affect root development of either species.

2. Anatomical Response

The tissues of rice and barnyardgrass were examined by light microcscopy. In cross sections, bundle sheath cell(BSC), mesophyll cell(MC) and bulliform cell(BC) of rice and barnyardgrass were observed. In longitudinal sections, leaf sheath(LS), leaf primordia(LP) and apex of stem(AS) of rice and barnyardgrass were observed. Plate 1 shows the anatomical structures of rice(Plate 1-A, B) and barnyardgrass(Plate 1-B, D) that were not treated with quinclorac. There is no anatomical change of vascular bundle sheath, leaf sheath and growing point of meristematic tissues in rice at 5 days after application regardless of seeding depth under dry conditions. But barnyardgrass under dry conditions has no anatomical effect in leaf morphology. However, leaf primordia and leaf sheath of barnyardgrass in cross sections of stem were constricted. The elongation of meristem in longitudinal sections of barnyardgrass stem were inhibited, and its cellular contents were partly lacked and vacuolated. At 10 days after application, quinclorac did not affect the anatomical traits of all rice under dry condition(Plate 2-A,

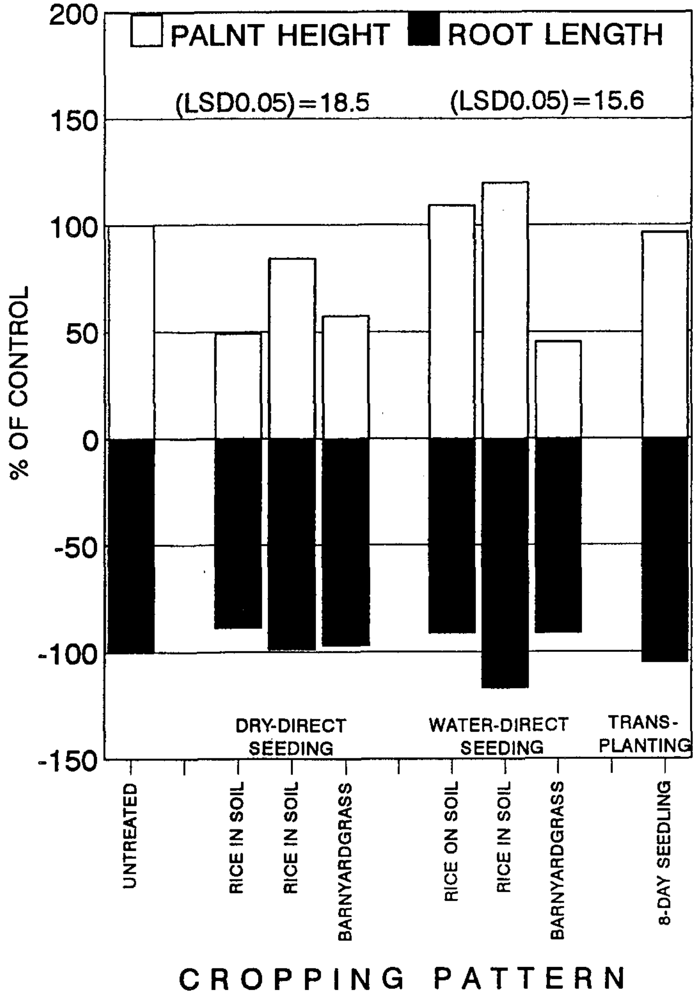


Fig. 1. Effect of quinclorac on plant height and root length of rice and barnyardgrass at 5 days after application. Application timing: 10 days after seeding.

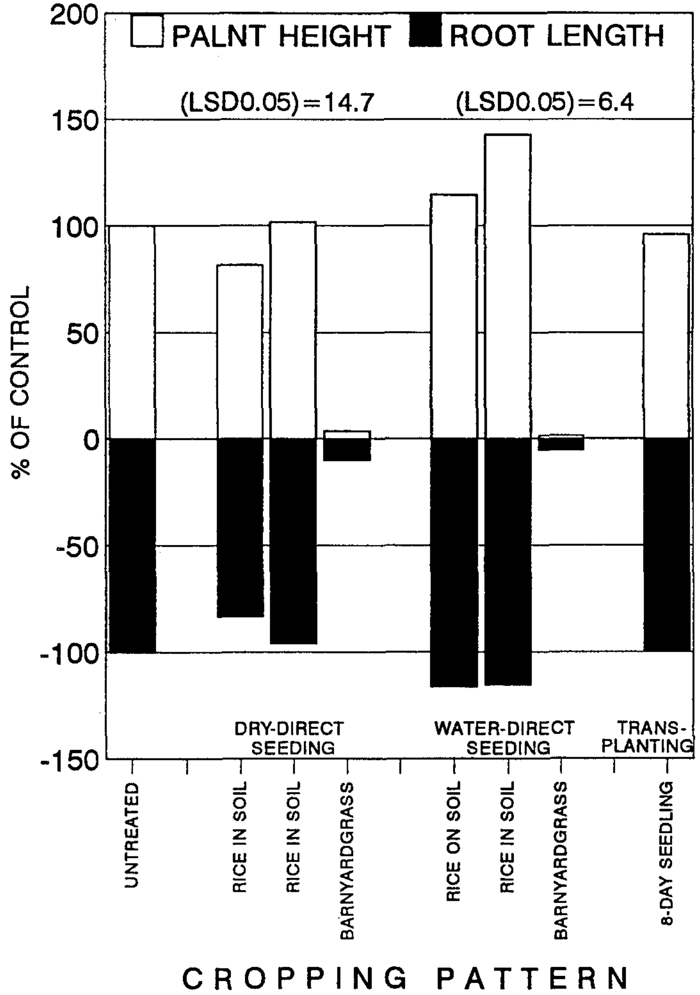


Fig. 2. Effect of quinclorac on plant height and root length of rice and barnyardgrass at 10 days after application. Application timing: 10 days after seeding.

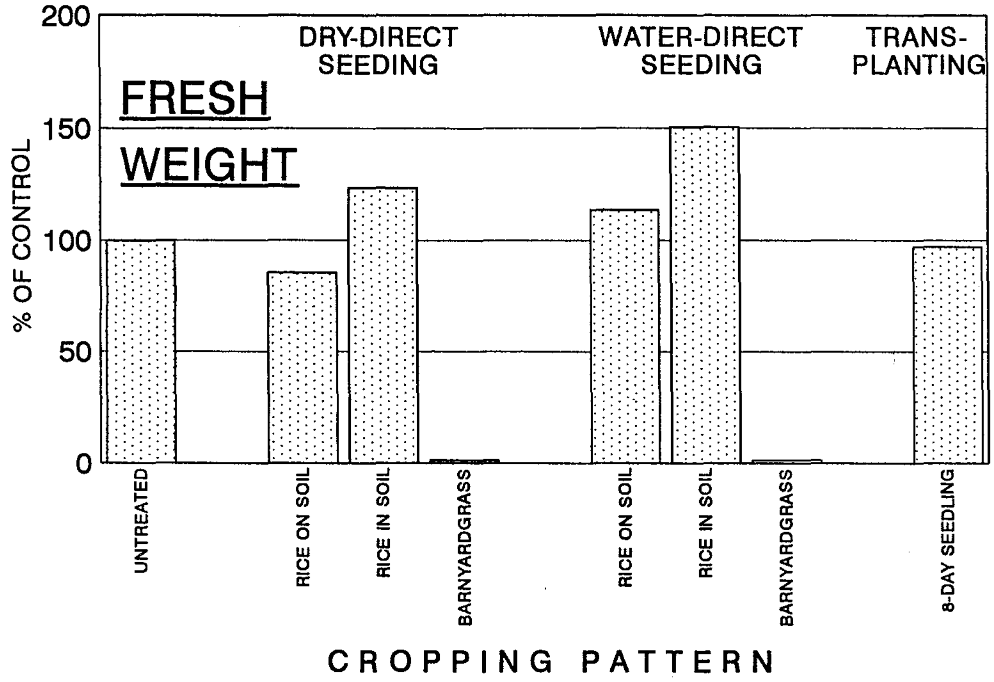


Fig. 3. Effect of quinclorac on shoot fresh weight(g/plant) of rice and barnyardgrass at 10 days after application. Application timing: 7 days after seeding.

D) while the leaf of barnyardgrass was discolored and become yellow color, thereby cells of leaf sheath and leaf primordia in stem were necrotic, and cell contents were disappeared, vacuolated, constricted and disrupted(Plate 2-B, C, E). Also, anatomical change of all water-seeded rice did not differ from that of dry-seeded rice 5 and 10 days after application but leaf morphology and meristematic tissue of barnyardgrass at 5 DAA were very slightly changed. Quinclorac changed leaf anatomical characteristic, and espicially disrupted chlorophyll of mesophyll cells. In this study, anatomical changes were supported by the distinct shrinkage observed in the bundle sheath cells and the loss of integrity of the interveinal mesophyll cells in barnyardgrass. At 10 days after application, we found that quinclorac caused necrosis and constriction of leaf primordia cells, lack of cell contents, inhibition of meristems elongation and necrosis of growing point in barnyardgrass(Plate 3-B, C, F). On the other hand, quinclorac did not affect leaf morphology and elongation of meristems in water seeded(Plate 3-A, D, E) transplanted rice. These studies showed that anatomical response to quinclorac was not clearly associated with growth of rice and barnyardgrass. Some reports(12, 13, 23) demonstrated that like quinclorac, some herbicides also caused constricted cells of the susceptible species and lack of cellular contents. Especially, Bellinder et al(6) reported that the activity of herbicides at the cellular levels appeared to be associated with membrane function and this idea is supported by the distinct shrinkage(12, 13, 24) in the bundle sheath cells and by the loss of integrity in the interveinal mesophyll of plant tested(7). The other reports(21, 22) demonstrated that the cells of the susceptible plants were vacuolated or non-nucleated and were abnormally enlarged by herbicide application.

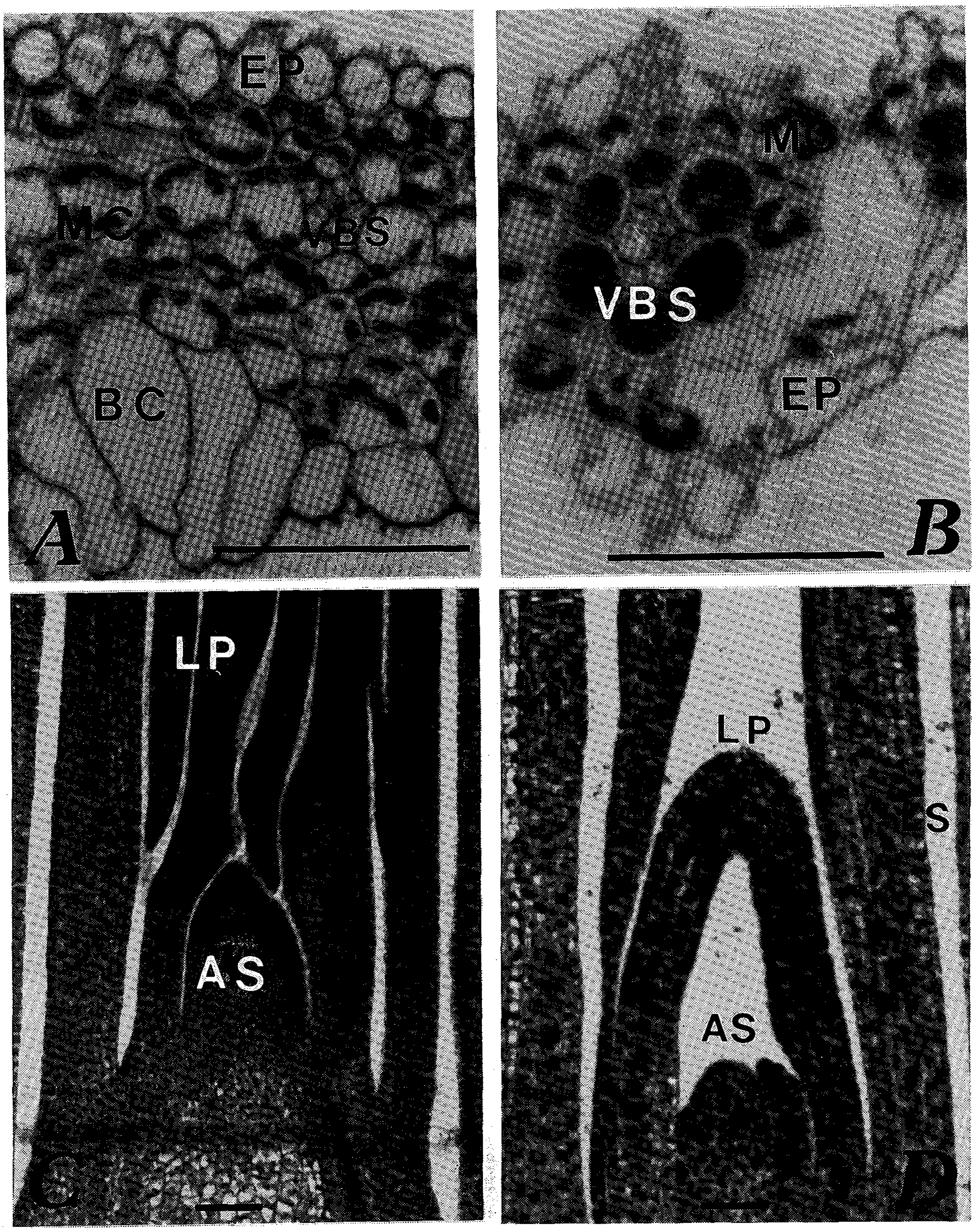


Plate 1. Cross sections(A, B) of leaves and longitudinal sections(C, D) of stems of untreated rice(A, C) and barnyardgrass(B, D) seedlings. EP: Epidermal cell, MC: Mesophyll cell, VBS: Vascular bundle sheath cell, BC: Bulliform cell, AS: Apex of stem, LP: leaf primordia and LS: Leaf sheath. Bars represent 10um.

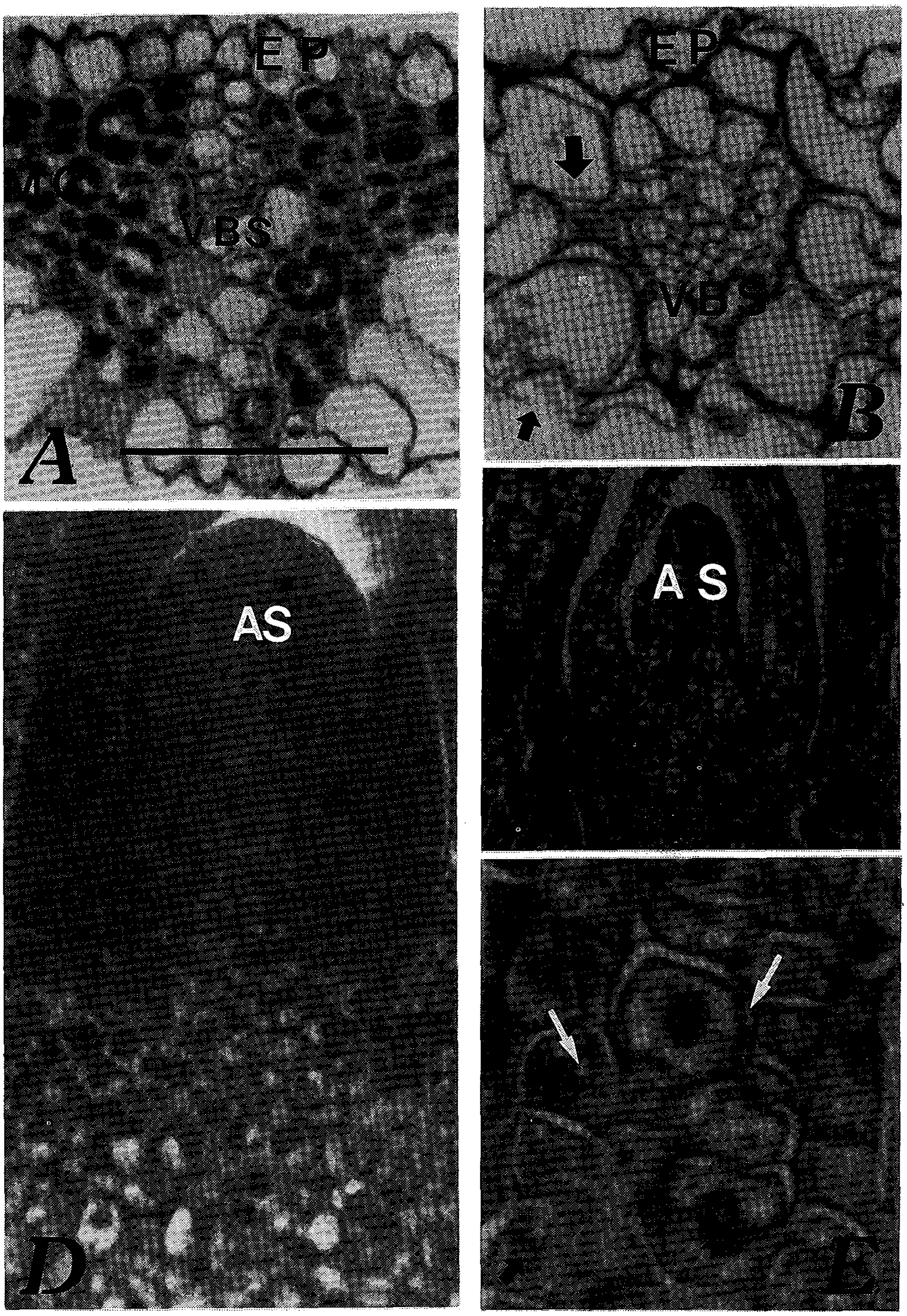


Plate 2. Cross section(A, B) of leaves and longitudinal sections(C, D, E) of stems of rice(A, D) and barnyardgrass(B, C, E) seedlings under dry seeding condition 10 days after quinclorac application. EP: Epidermal cells, MC: Mesophyll cell, VBS: Vascular bundle sheath cell, BC: Bulliform cell, AS: Apex of stem, LP: leaf primordia and LS: Leaf sheath. Bars represents 10um. Note lacked cellular cytoplasm(B), necrotic meristems(C) and swelling cells(E) of barnyardgrass.

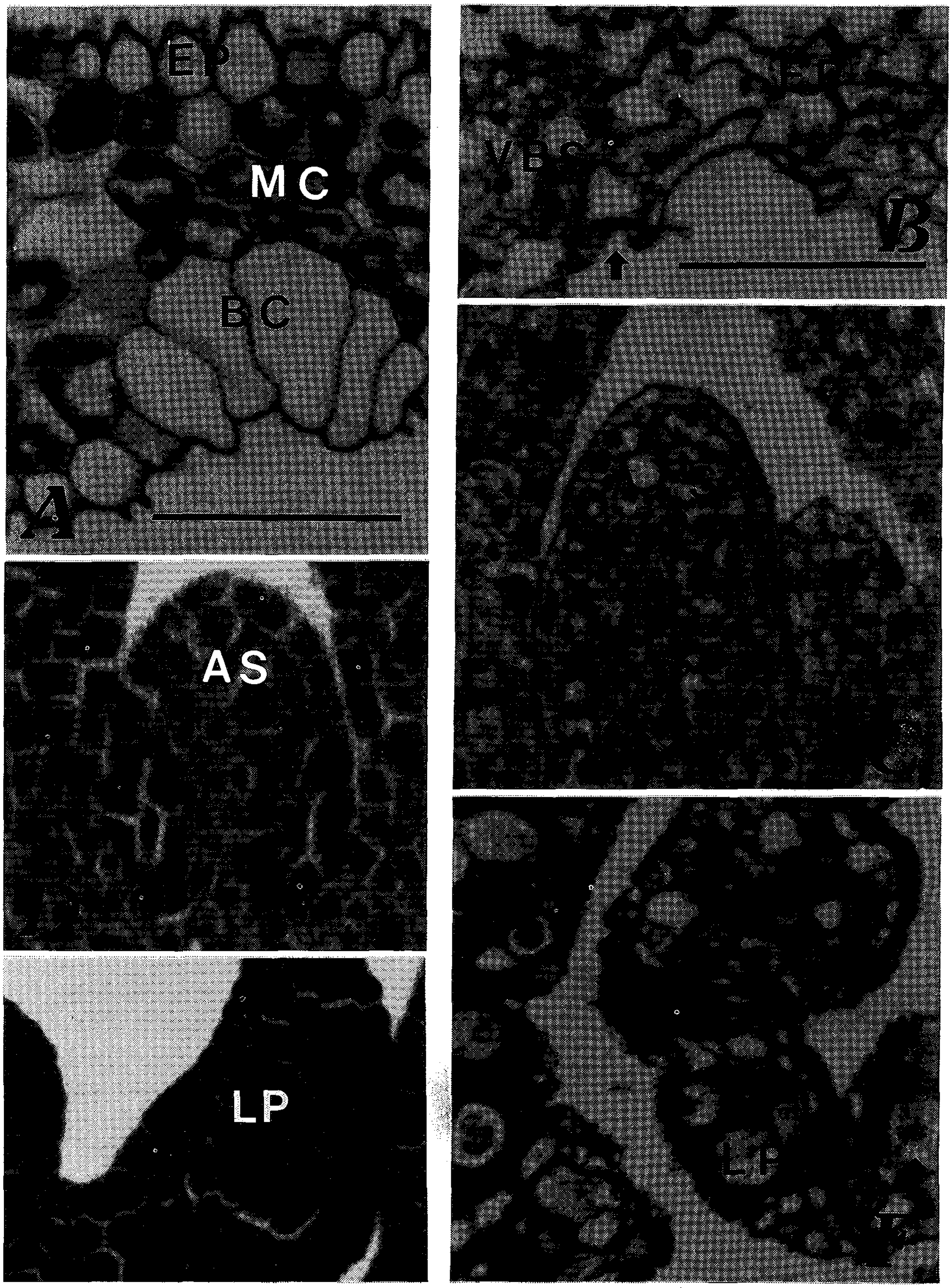


Plate 3. Cross sections(A, B, E, F) of leaves(A, B) and longitudinal sections(C, D) of stems of rice(A, D, E) and barnyardgrass(B, C, F) seedlings under water seeding condition 10 days after quinclorac application. EP: Epidermal cells, MC: Mesophyll cell, VBS: Vascular bundle sheath cell, BC: Bulliform cell, AS: Apex of stem, LP: leaf primordia and LS: Leaf sheath. Bars represents 10um. Note costricted cells(B), lacked nucleus(B, F), necrotic meristem(C) and lacked cellular cytoplasm(F) of barnyardgrass.

Literature cited

1. Guh, J. O., S. U. Han and S. U. Chon. 1993. Tank-mix feasibility reducing the application rate of quinclorac. Korean J. of Weed Sci. 13(1):14-18.
2. Beck J. and S. Kashibuchi. 1988. Activity of spray-applied quinclorac and combination on rice and weeds. Weed Res. Japan. 33(Sup.):21-22.
3. Kießling, U. and A. Zoscke. 1989. Facet, a new herbicide for weed control in various production systems in seeded rice. 12th APWSS Conf. Proceeding:571-579.
4. Berghaus, R. and B. Wurzer. (1987). The mode of action of the new experimental herbicide Quinclorac(BAS514H). Proceedings Asian-Pacific Weed Science Society. 11th Conf.
5. Smith, Roy J. (Jr). 1983. Integrated weed management in rice in the USA. Korean J. Weed Science 3(1):1~13.
6. Bellinder, R. R., R. E. Lyons, S. E. Scheckler, and H. P. Wilson. 1987. Cellular alterations resulting from foliar application of HOE-398665. Weed Sci. 35:27-35.
7. Morrison, I. N., B. D. Hill, and L. G. Dushnicky. 1979. Histological studies on the effects of benzoyprop-ethyl and flamprop methyl on growth and development of wild oats. Weed Res. 19:385-393.
8. Herbst, K. A. and J. F. Derr. 1990. Direct-seeded Broccoli(*Brassica oleracea* var. *botrytis*) response to oxyfluorfen and BAS514 applied preemergence. Weed Tech. Vol 4:356-359.
9. Guh, J. O. , W. H. Im, S. U. Han and Y. I. Kuk. 1992. Application rate motification of paddy herbicide quinclorac depending on different cultural patterns. Korean J. Weed Sci. 12(2):124-131.
10. Hong, S. Y., I. J. Lee, K. U. Kim, D. H. Shin, and C. N. Lee. 1993. Physiological and anatomical studies of quinclorac action. Korean J. Weed Sci. 13(1):62-70.
11. Menck, B. H., H. Rosebrock, W. Unglaub, and E. Kibler. 1985. BAS514H -quinclorac field experience to control *Echinochloa crus-galli* in rice. The 10th APWSS Conf.:107-113.
12. Chon, S. U., J. O. Guh, and Y. J. Kim. 1994. Morphological characteristics of growth of rice and barnyardgrass under various cropping patterns. Ⅳ. Difference in morphological and anatomical response to butachlor. Korean J. Weed Sci. 14(3):199-211.
13. Chon, S. U., J. O. Guh, and S. L. Kwon. 1994. Morphological characteristics of growth of rice and barnyardgrass under various cropping patterns. Ⅴ. Difference in morphological and anatomical response to thiobencarb. Korean J. Weed Sci. 14(3):212-222.
14. Kang, B. H. 1984. Metabolism von ^{14}C-Chlorsulfuron verschieden empfindli - chen Kulturphlanzen and Unkraytern. 4(2):115-124.
15. Smith, R. J., Jr. 1968. Weed competition in rice. Weed Sci. 16:252-254.
16. Seaman, D. E. 1983. Farmer's weed control technology for water-seeded rice in Northern America. pp 167-177. In Proc. Conf. Weed Control in Rice. Int. Rice. Res. Inst., Los Banos, Laquna, Philippines.
17. Park, S. T., S. C. Kim, Y. Son and K. S. Jung. 1990. Study on the major cultivation method dry seeded rice in Youngnam area. Report of Agri. Report(Rice) 32(2):18-28.
18. Nakayawa, H. 1981. Study on the cultivation of water-subsoil seeded rice by use of transplanting machine. Ishida Agri. Exp. Rep. 11:1-28.
19. Bayer, D. E. and J. E. Hill. 1989. Weed Control Practices and Problems in direct-seeded rice. Conf. of 12th APWSS. Proc 53-56.
20. O'Brien, T. D., M. E. McCully. 1981. The study of plant structure principles and selected methods. p. 280.
21. Shibayama. H. and J. F. Worley. 1976. Growth responses of barnyardgrass and beared sprangletop seedlings to thiobencarb Weed Sci. 24:276-281.
22. Chon, S. U., J. O. Guh, Y. M. Lee and D. J. Lee. 1988. Anatomical difference between two rice cultivars selected to bensulfuron. Korean J. Weed Sci. 8(3):219-236.
23. Hosaka, H., H. Inaba, A. Satoh and H. Ishikawa. 1984. Morphological and histological effects of sethoxydium on corn(*Zea mays*) seedlings. Weed Sci. 32:711-721.
24. Jain, R. and W. H. Vanden Born. 1989. Morphological and histological effects of three grass selective herbicides on developing wild oat(*Avena fatua*) Stems. Weed Sci. Vol. 37:575-584.

Pretilachlor as a Tool for Modern Weed Control in Transplanted Rice in Japan

A. Nakamura*, S. Murakami, J. Adachi and J-L. Allard**
Ciba-Geigy Japan, Agricultural Division, Tokyo 105, Japan
** Ciba-Geigy, CH-4002 Basel, Switzerland

Abstract. To meet the needs of reduced cost and labor, weed control technologies in Japanese rice cultivation have changed considerably over the last ten years. Sequential application of herbicides has been largely replaced by "one-shot" applications and formulations have become more diversified. In this paper, we show that pretilachlor use has been adapted to meet these changes. The field trials were carried out at Ono Station in Hyogo pref. on a sandy loam soil, and a greenhouse trial was made using Ono soil. The results show that pretilachlor at 400 gai/ha has an excellent duration of activity against *E. oryzicola*, annual dicots and sedges when applied pre-emergence followed by a one-shot herbicide. The application period of pretilachlor (450 gai/ha) can be extended to more than 2.5 leaf stage of *E. oryzicola* in combination with esprocarb at 1500 gai/ha. New formulations of pretilachlor, such as 10 kg/ha granule, EC and Jumbo formulation, show equivalent performance to 30 kg/ha granule. It can be concluded that pretilachlor is a flexible and valuable tool for the control of *E. oryzicola*, annual dicots and sedges in modern Japanese rice cultivation.

Key words. pretilachlor, herbicidal activity, transplanted rice, new formulations, one-shot herbicide

Introduction.

Pretilachlor was discovered and developed by Ciba-Geigy [1] and was introduced in Japan in 1984 as Solnet™ 2% granules (GR2) and as a component of several mixtures. Over the last ten years, the requirements for weed control in Japanese rice cultivation have changed: for example, reduction of weed control cost (herbicide cost x number of applications), needs for easier application methods, shift of weed flora to hard-to-kill perennials and reduced environmental impact.

So called "one-shot" herbicides partly meet the above mentioned requirements, however, serial application of herbicides is still necessary in cool climate areas where weeds emerge and grow slowly and where hard-to-kill perennials are present [2) 3)].

We have been adapting pretilachlor use recommendations in different ways to meet these changes. Pre-emergence application of pretilachlor at reduced dosage has been studied as a serial treatment followed by a one-shot herbicide. The performance of pretilachlor as a component of a one-shot herbicide has been clarified in mixture with esprocarb. In addition, new formulations have been or are being developed; such as 4% granules at the application volume of 10 kg per hectare (here after 10 kg/ha GR) which can reduce application volume to one third as compared to the conventional 2% granules (30 kg/ha GR), 12% emulsifiable concentrate (EC120) which can be dripped into rice paddy fields without dilution and 4% granules in water soluble bag (Jumbo) which can be thrown into fields by hand at 200 bags per hectare.

This paper shows the efficacy of pretilachlor 1) as a pre-emergence herbicide at reduced dosage followed by a one-shot application 2) as a component of one-shot in mixture with esprocarb and 3) of new formulations.

Materials and Methods.

Field trials were conducted at Ono Station in Hyogo Prefecture on a sandy loam soil during 1991 to 1994. Plot size was 3 m^2 with two to three replications. Irrigation and puddling were done a day prior to the transplanting. Greenhouse trial was carried out with 1/10,000a Wagner pots containing Ono soil with three replications.

1. Pre-emergence application of pretilachlor

1.1. Duration of activity under greenhouse conditions

Pretilachlor GR2 at 300, 450 and 600 gai/ha were applied seven times from 46 to 0 days before the sowing of *Echinochloa oryzicola* Vasing. (here after ECHOR). Top fresh weight of ECHOR was measured 16 days after sowing.

1.2. Performance of pretilachlor at 400 gai/ha under field conditions

Pretilachlor GR2 at 400 gai/ha was applied three days after transplanting. Leaf stage (average across the five biggest plants in the plot) and weed number in a 260 cm^2 section were recorded on ECHOR, *Scirpus juncoides* Roxb. var. *ohwianus* T. Koyama (SCPJO) and *Monochoria vaginalis* (Burm. f.) Presl var. *plantaginea* (Roxb.) Solms-Laub. (MOOVP).

2. Pretilachlor as a mixing partner with esprocarb

Pretilachlor GR2 at 450 gai/ha, esprocarb GR5 at 1500 gai/ha and their mixture were applied 7, 10 and 14 days after transplanting. The leaf stage of weeds at application is shown in Table 1. The activity on ECHOR, SCPJO, MOOVP and annual broadleaved weeds was visually assessed 41 days after transplanting on a 0 - 100 % scale.

Table 1: Leaf stage of weeds at application

Application timing*	ECHOR	SCPJO	MOOVP	Annual broad leaf weeds
7	2.1	1.0	1.0	2.0
10	2.4	2.0	1.5	2.0-3.0
14	3.3	3.3	2.8	3.0

*: Days after transplanting

3. New formulations of pretilachlor

New formulations of pretilachlor were compared in field trials; 10 kg/ha GR versus 30 kg/ha GR at 400 gai/ha, EC120 versus 30 kg/ha GR at 600 gai/ha and Jumbo versus 10 kg/ha GR at 400 gai/ha. The products were applied two to four days after transplanting. Weed control was assessed visually 24 to 30 days after transplanting on a 0 - 100% scale. For the Jumbo formulation, assessment was done at three different spots (0-1 m, 1-3 m and 3-5 m) from the applied spot to determine the spreadability of the product.

Results.

1. Pre-emergence application of pretilachlor

1.1. Duration of activity under greenhouse conditions

More than 50 % control on ECHOR lasted for 23, 28 and 35 days at 300, 450 and 600 gai/ha respectively (Figure 1).

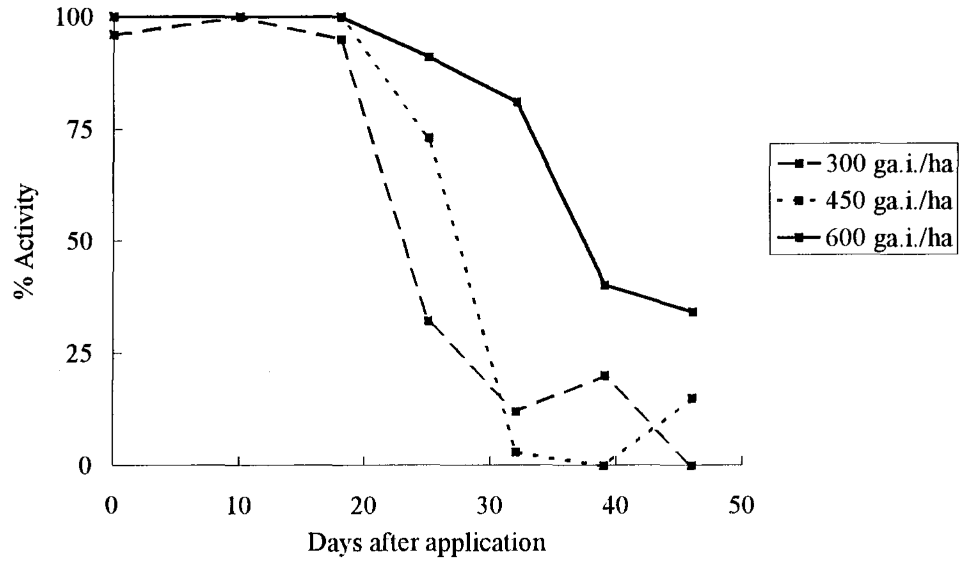


Figure 1: Duration of activity of pretilachlor on ECHOR in greenhouse conditions

1.2. Performance of pretilachlor at 400 gai/ha in field conditions

Pretilachlor GR2 at 400 gai/ha delayed emergence and development of ECHOR by more than ten days. Emerged number of ECHOR was reduced from 500 plants/m^2 to 5 plants/m^2 22 days after transplanting (Figure 2). Pretilachlor at 400 gai/ha also delayed the emergence of MOOVP by eight days, and reduced number from 260 to 30 plants/m^2 28 days after transplanting (Figure 3).

Emergence of SCPJO was not observed on plots treated with pretilachlor until 28 days after transplanting, whereas in check plots the leaf stage and number of SCPJO had reached 3.1 leaf stage and 260 plants/m^2, respectively.

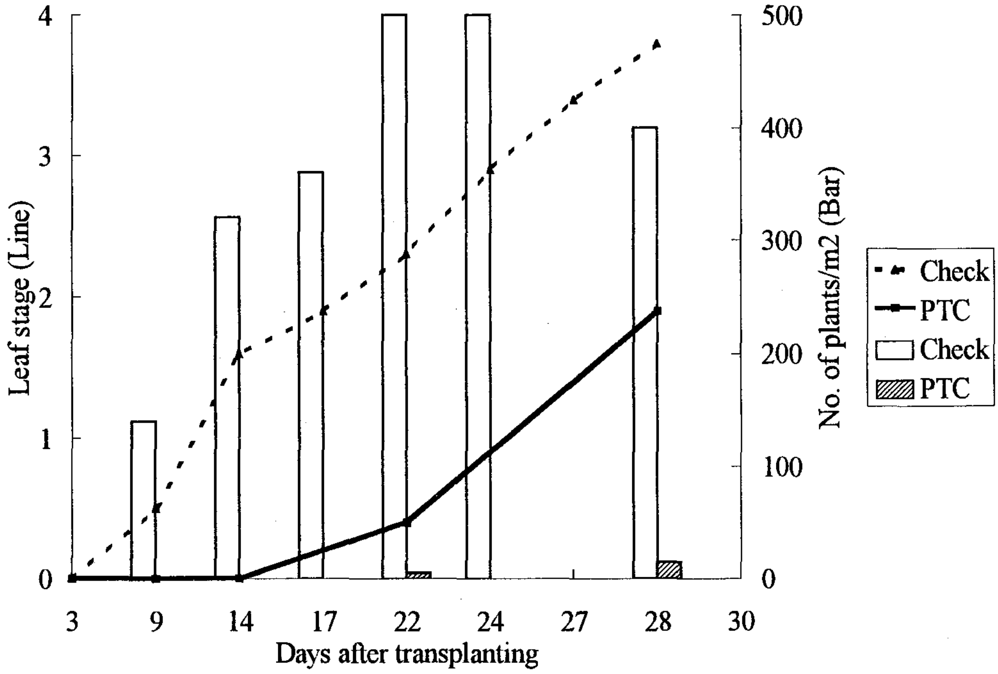


Figure 2: Effect of pretilachlor at 400 gai/ha on the emergence and growth of ECHOR

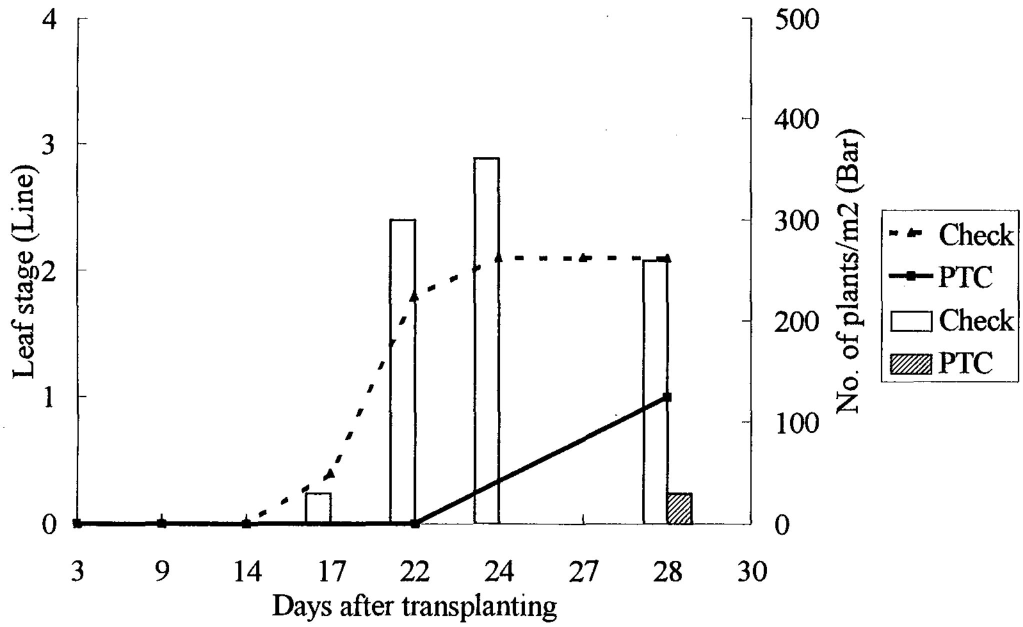


Figure 3: Effect of pretilachlor at 400 gai/ha on the emergence and growth of MOOVP

2. Pretilachlor as a mixing partner with esprocarb

The mixture of pretilachlor with esprocarb at 450 + 1500 gai/ha controlled ECHOR excellently up to 3.3 leaf stage, Activity of the mixture on SCPJO, MOOVP and annual broadleaved weeds was better than each component of the mixture applied separately (Table 2).

Table 2: Activity of pretilachlor at 450 gai/ha in mixture with esprocarb at 1500 gai/ha

Appli. timing (Leaf stage of ECHOR)	Compounds	Dosage (gai/ha)	Weed control (0-100% scale)			
			ECHOR	SCPJO	MOOVP	ABLW*
2.1	pretilachlor	450	100	94	73	95
	esprocarb	1500	99	95	87	52
	pretila.+esprocarb	**450+1500**	**99**	**98**	**99**	**100**
2.4	pretilachlor	450	93	83	75	95
	esprocarb	1500	95	67	55	38
	pretila.+esprocarb	**450+1500**	**98**	**94**	**83**	**98**
3.3	pretilachlor	450	50	45	35	54
	esprocarb	1500	82	77	65	26
	pretila.+esprocarb	**450+1500**	**98**	**90**	**79**	**69**

*: Annual broadleaved weeds

3. New formulations of pretilachlor

The performance of the new formulations, 10 kg/ha GR and EC120, was equivalent to that of 30 kg/ha GR against ECHOR, SCPJO, MOOVP and annual broadleaved weeds. The activity of Jumbo formulation was comparable to that of 10 kg/ha GR at up to 5 m from the applied spot. All the formulations had excellent crop tolerance against transplanted rice (Table 3).

Table 3: Phytotoxicity and activity of new formulations of pretilachlor

Trial	Formulations	Dosage (gai/ha)	Distance from applied spot	Phytotoxicity to rice and weed control (0-100% scale)				
				Phyto.	ECHOR	SCPJO	MOOVP	ABLW*
1	10 kg/ha GR	400	-	5	100	100	98	98
	30 kg/ha GR	400	-	9	99	98	98	99
2	EC120	600	-	10	98	98	96	95
	30 kg/ha GR	600	-	8	95	99	99	98
3	Jumbo	400	0-1m	3	99	97	100	100
			1-3 m	0	98	94	100	100
			3-5 m	0	89	84	89	97
	10 kg/ha GR	400	-	5	85	93	98	97

*: Annual broadleaved weeds

Discussion.

The duration of pre-emergence applied pretilachlor activity on ECHOR varies depending on dosage. This makes possible for farmers to adapt the dosage of pretilachlor according to their desired period of weed suppression (= period between pretilachlor application and one-shot herbicide application). At 400 gai/ha, the emergence of ECHOR, SCPJO and other annual weeds is delayed by more than one week. This is sufficient in serial treatments with a one-shot herbicide to obtain excellent control of weeds in areas where weeds emerge and grow slowly due to cool climate and where hard-to-kill perennials are present. This reduced dosage fit well farmer's needs concerning weed control, improves cost efficiency and reduces environmental impact.

Pretilachlor at 450 gai/ha in mixture with esprocarb provides excellent control of ECHOR from pre-emergence to more than 2.5 leaf stage, and also improves the control on other annual weeds. This mixture, complemented by a sulfonylurea for the control of perennial weeds, can be used as a base for the development of new one-shot herbicides with excellent application timing flexibility.

Performance of the new formulations of pretilachlor (10 kg/ha GR, EC120 and Jumbo) is equivalent to conventional 30 kg/ha GR. In addition, these new formulations offer flexible choice of application methods to farmers according to the size of fields and their needs.

Through the development of new use recommendations (lower dosage, mixtures with esprocarb and low volume formulations) for pretilachlor, it can be concluded that this active ingredient fulfills well the requirements of weed control in modern Japanese rice cultivation. Herewith, a high level of weed control can be achieved with flexible application timing and methods together with a reduced environmental impact.

References.

1. MURAKAMI, S. and EBNER L. (1983): Pretilachlor - A new selective herbicide for transplanted rice in Japan. Proc. Ninth Conf. Asian-Pacific Weed Sci. Soc., 532-538.
2. OGIWARA, T. (1985): Present status and some problems of weed control in paddy rice cultivation - Cool region. Weed Res. Japan 30(3), 181-188.
3. TANIKAWA, K. (1985): Present status and some problems of weed control in paddy rice cultivation - Cold region. Weed Res. Japan 30(3), 177-181.

EFFECT OF WATER STRESS ON GLYPHOSATE PHYTOTOXICITY: HISTOLOGICAL STUDY OF *IMPERATA CYLINDRICA* (L.) RAEUSCHEL.

P. Wanichanantakul and K. Pongern
Department of Agriculture, Chatuchak, Bangkok 10900, Thailand

Abstract. Glyphosate (N-(phosphonomethyl-glycine) has proved to be an effective herbicide for controlling *Imperata cylindrica* with foliar application under normal conditions, while for drought stress it was less effective. A histological study investigated the nature of the phytotoxic action of glyphosate on cell structures of plants grown under non-water stressed and water stressed conditions. Transverse sections of leaves treated with glyphosate did not affect leaf anatomy or membrane integrity. There were no anatomical barriers to the entry of glyphosate into the plants, but stressed plants (leaf water potential -1.2 MPa) displayed significant barriers. Plants grown under water stressed conditions had thicker outer and inner bundle-sheaths, and thick cuticles. Bulliform cells and vascular bundles became deflated and disorganized and loss their oval shape. If plants were severely water stressed xylem, phloem and bulliform cells collapsed, and phloem cells were broken and disappeared as compared to the non-stressed plants, whose epidermis, bulliform cells and vascular bundles were well defined and organized. Water stress showed a significant effect on leaf anatomy and resulted in reducing glyphosate activity.

Key words. Histological study, anatomy, water stress, glyphosate, *Imperata cylindrica*

Introduction

Glyphosate is effective for controlling *I. cylindrica* as a foliar application, it is translocated throughout the plant and accumulated at the meristematic tissues of roots and rhizomes. However, the herbicide must first penetrate the cuticle, which covers the entire surface of leaf. Plants growing under water stressed conditions often develop thickened cuticles and walls, which influence the uptake and translocation of herbicides. Klevorn and Wyse (1984) reported that uptake and translocation of ^{14}C-glyphosate into leaves to daughter shoots and roots and rhizome buds of quack grass (*Agropyron repens)* under water stress were reduced. The objective of this study was to investigate the effect of water stress on cell structures and the anatomical effect of water stress on glyphosate phytotoxicity on plants grown in the glass house and field.

Materials and Methods

The normal leaves of *I. cylindrica* were collected from plants growing under non-water stressed (field capacity) and stressed conditions (Leaf water potential -1.2 MPa) in a glass house. Leaf samples were also collected from plants growing in the field trials at the Chachoengsao Rubber Research Centre, in the rainy (soil moisture content 13-16 %) and dry seasons (soil moisture content 5-7 %). Plants were sprayed with glyphosate (Roundup, 48 % a.i.) at the rate of 2 and 3 kg a.i./ha and harvested 24, 72, 120 and 168 hours later. Five leaves were cut from treated and non-treated plants of each treatment, the middle part of the leaf of *I. cylindrica* was cut into 5x7 mm sections with a sharp razor blade to avoid bruising the tissues. After cutting, the sections were immediately placed into FAA solution. The tissues were stained with Safranin-O and Fast Green solution. After staining, the slides were dried in an incubator at 40-50 °C for 1 to 2 days before storing in slide boxes. They were then ready for examining under a light microscope. Fixing, dehydrating, embedding, staining and mounting were based on the methods of Johansen (1940).

Results and Discussion

Effect of water stress on the glyphosate phytotoxicity on the aerial shoots of *I. cylindrica.*
Application of glyphosate on *I. cylindrica* at the rainy season, glyphosate induced chlorosis, wilting and collapse of shoots. The highest rate showed symptoms of phytotoxicity within 1 week after treatment. Two months after treatment, the shoots had completely turned brown and collapsed. No new emerging shoots were observed in the next rainy season. Application of glyphosate at the dry season was not effective, the symptom seemed to be more the result of drought stress than herbicide treatment. Shoots became brown and most had died-back during the dry season. New emerging shoots

were observed when plants were returned to normal conditions and become dense population in the rainy season.

Effect of water stress on plant tissues

Plate A showed plant growing under non-water stressed conditions (rainy season). Transverse sections of *I. cylindrica* leaf showed good development of epidermal cells, cuticle, wall, outer and inner bundle sheaths, bulliform cells, vascular bundles and all their walled cells were thin. Mesophyll was green and containing more green pigments (chloroplasts) in the outer bundle sheaths than those of the outer bundle sheaths of the stressed plants. It was common to find a high proportion of both small and big vascular bundles not accompanied by sclerenchyma. The internal structure of leaf was typical of a C_4 plant and showed kranz anatomy. Plates B and C showed plants growing under water stressed conditions, in the field and glass house respectively. Dry conditions caused stomata to close and cells became mostly flaccid and collapsed, severe water stress (Plate C), sclerenchyma was well developed and with markedly thicker walled cell, the xylem elements became thicker, vascular bundle more disorganized, and lose their oval shape, phloem tissues became broken and the sieve tubes and companion cells disappeared leaving a big cavity, Crystals were mostly found in the leaves of plants grown in the dry season rather than the wet season.

Anatomical effect of water stress on glyphosate phytotoxicity

Transverse section of *I. cylindrica* leaves of plants grown in the field and glass house under non-water stressed conditions and treated with glyphosate at 2 and 3 kg a.i./ha. No injury on cell structures was observed to be caused by glyphosate, even when the plants had been treated at the higher rate during 1-7 days of treatment, with the epidermal cells, cuticle, wall, outer and inner bundle-sheaths bulliform cells and vascular bundles all normal conditions (Plate D). There was no sign of herbicide deposits in the treated leaves. Plants grown under stressed conditions in the glass house (Plates E) and field (Plate F) sprayed with glyphosate at the rate of 2 and 3 kg a.i./ha showed deposits of small darkened spots in phloem cells, especially the companion cells both of big and small vascular bundles (Plate E and C), but the untreated control, showed no evidence of black spots on any cell (Plate B and C). Possibility, the black spots were glyphosate retaining in the treated leaves which could not translocate out of the treated leaves compared to unstressed plants treated with glyphosate little or no deposition of black spots in the treated leaves. The histological study showed that 7 days of treatment, normal plants treated with glyphosate at the highest rate, had cell structures still well defined. This implied that glyphosate had no primary effect on membrane integrity. The results agreed with the histological results of Canal *et al.,* (1990) on glyphosate injury to *Cyperus esculentus* leaves and basal bulbs which indicated that glyphosate did not affect leaf anatomy but only light necrotic was seen on the vein. Devine, Duke and Fedtke (1992) used micro-autoradiography of soybean stem sections treated with ^{14}C-picloram to show that ^{14}C was localized in the vascular bundle; phloem and xylem cells. The changes in all structures result from drought stress, all helps to explain the reduced uptake and translocation of glyphosate measured in stressed plants.

Abbreviation used in the plates

BU = Bulliform cell	MX = Metaxylem	ME = Mesophyll
CH = Chloroplast	CW = Cell wall	ST = Stomata
VS = Vascular bundle	CU = Cuticle	PH = Phloem
CO = Sclerenchyma	XY = Xylem	EP = Epidermis
SC = Upper epidermis	LEP = Lower epidermis	
OBS = Outer bundle-sheath	IBS = Inner bundle-sheath	

Acknowledgment : I am deeply indebted to Dr. C.E. Price, Imperial College, London University for his valuable advice and guidance. Thank is due to the staffs of the Botany section, Botany and Weed Science Division, Department of Agriculture, Thailand, for their helps.

References

Canal, M.J., R. Albuerne, R.S. Tames and B. Fernandez. 1990. Glyphosate injury *Cyperus esculentus* leaves and basal bulbs: histological study. *Weed Research*, 30, 117-122.

Devine, M.D., S.O. Duke and C. Fedtke. 1992. *Physiology of herbicide action*, pp. 441. PTR Prentice Hall, Englewood Cliffs, New Jersey.
Johansen, D.A. 1940. *Plant micro technique*, pp. 523. McGraw-Hill Publication in the Botany Sciences.
Klevorn, T.B. and D.L. Wyse. 1984. Effect of leaf girdling and rhizome girdling on glyphosate transport in quack grass (*Agropyron repens*). *Weed Science*, 32, 744-750.

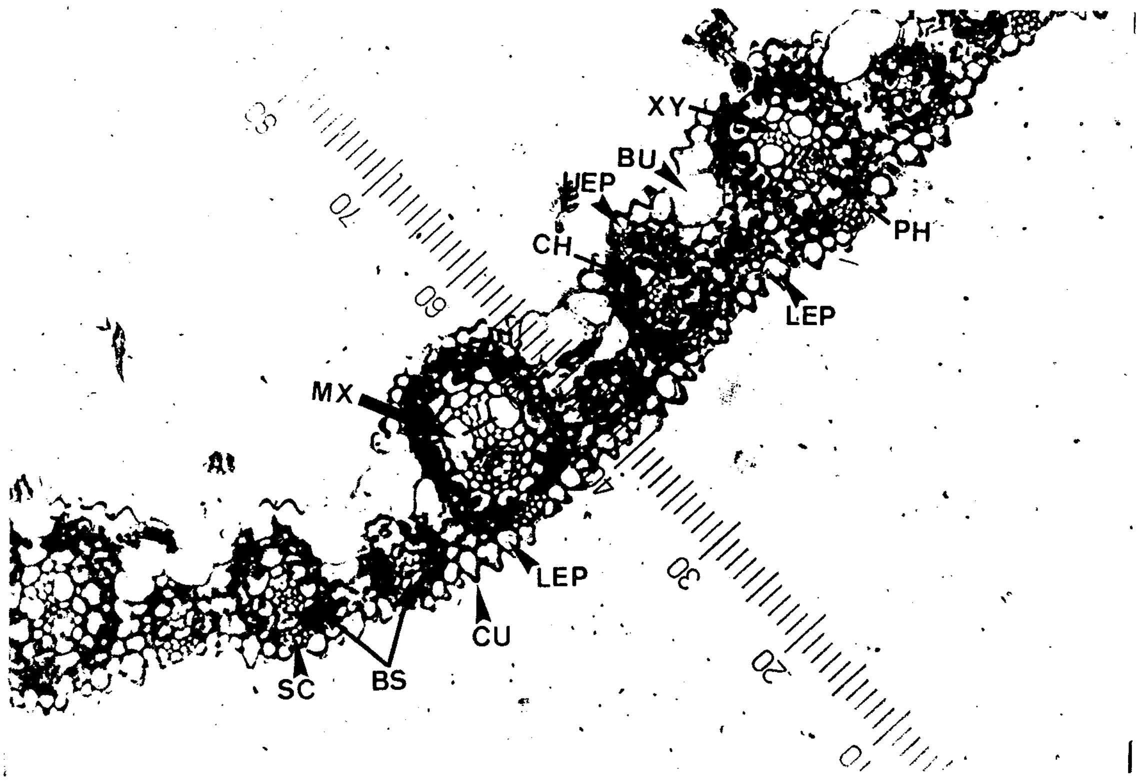


Plate A. Transverse section (20 x 2.5) of *I. cylindrica* leaf collected from plant growing in the field, under non-water stress conditions showing well developed vascular bundles, bulliform cells and mesophyll cells.

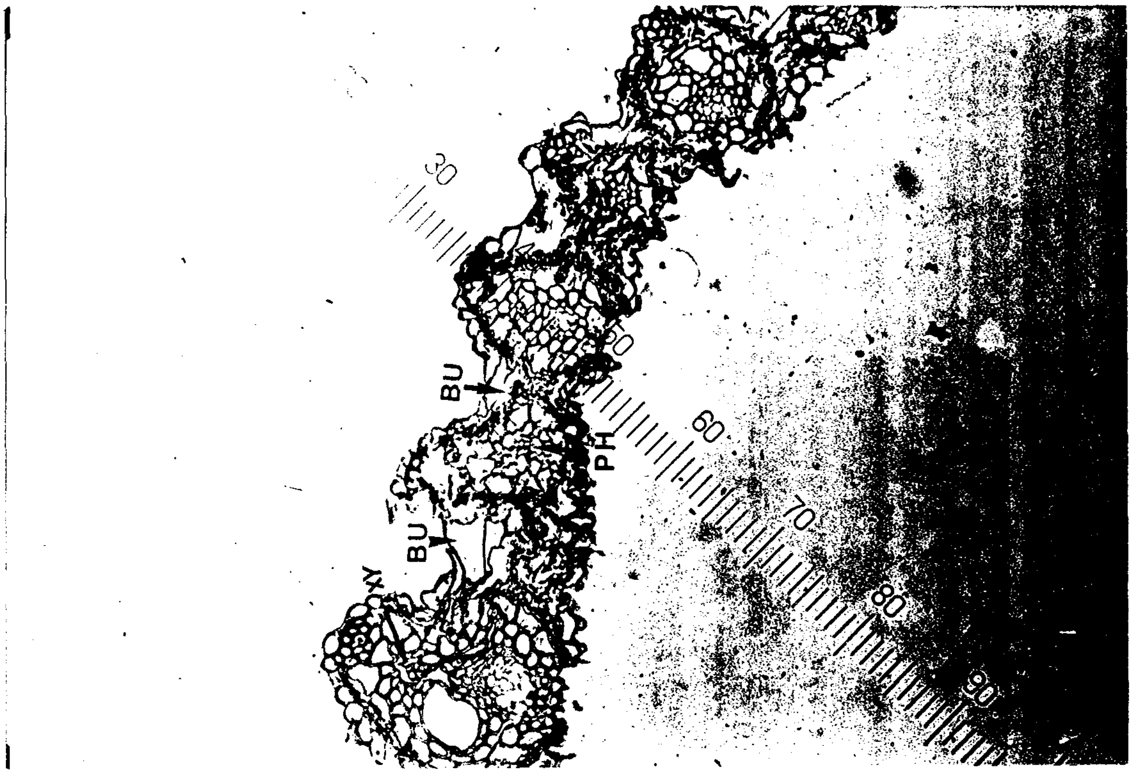


Plate B. Transverse section (20 x 2.5) of *I. cylindrica* leaf collected from plant growing in the glass house, under water stressed conditions, showing disorganized vascular bundles and collapsed cells.

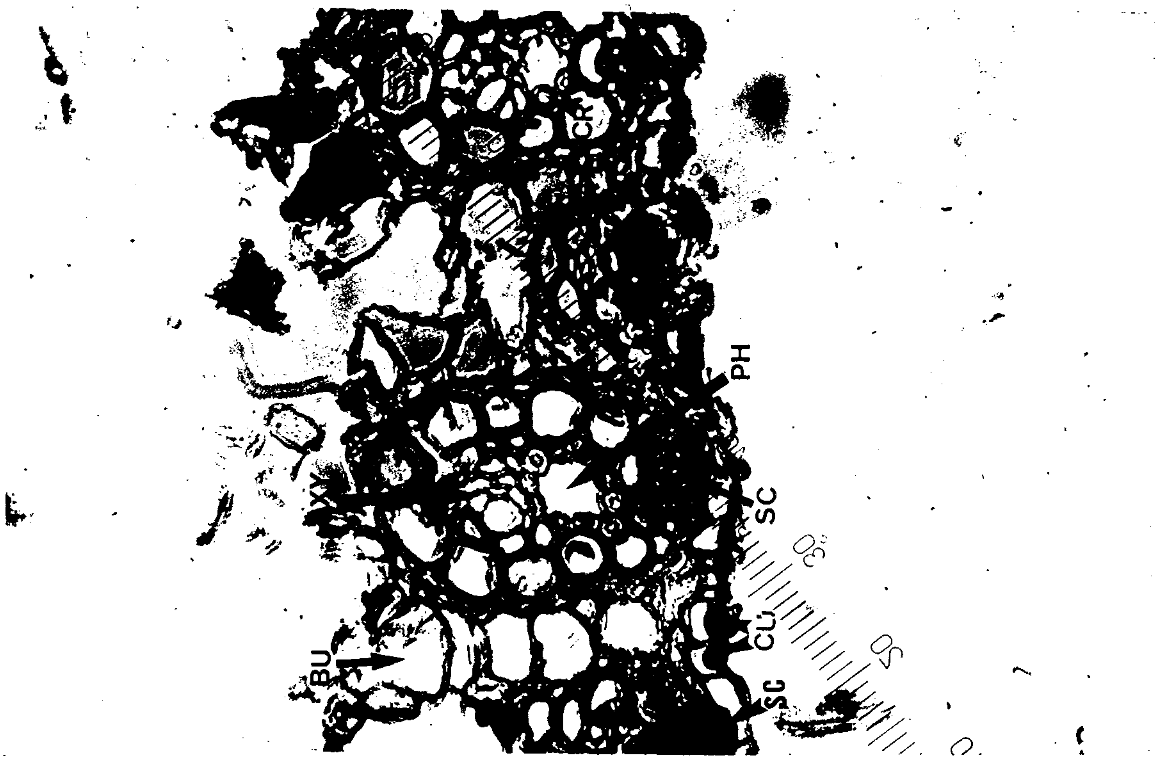


Plate C. Transverse section (20 x 2.5) of *I. cylindrica* leaf collected from plant growing in the field, under water stressed conditions, showing disorganized vascular bundles, phloem cells were broken, and well developed sclerenchyma and crystal cells.

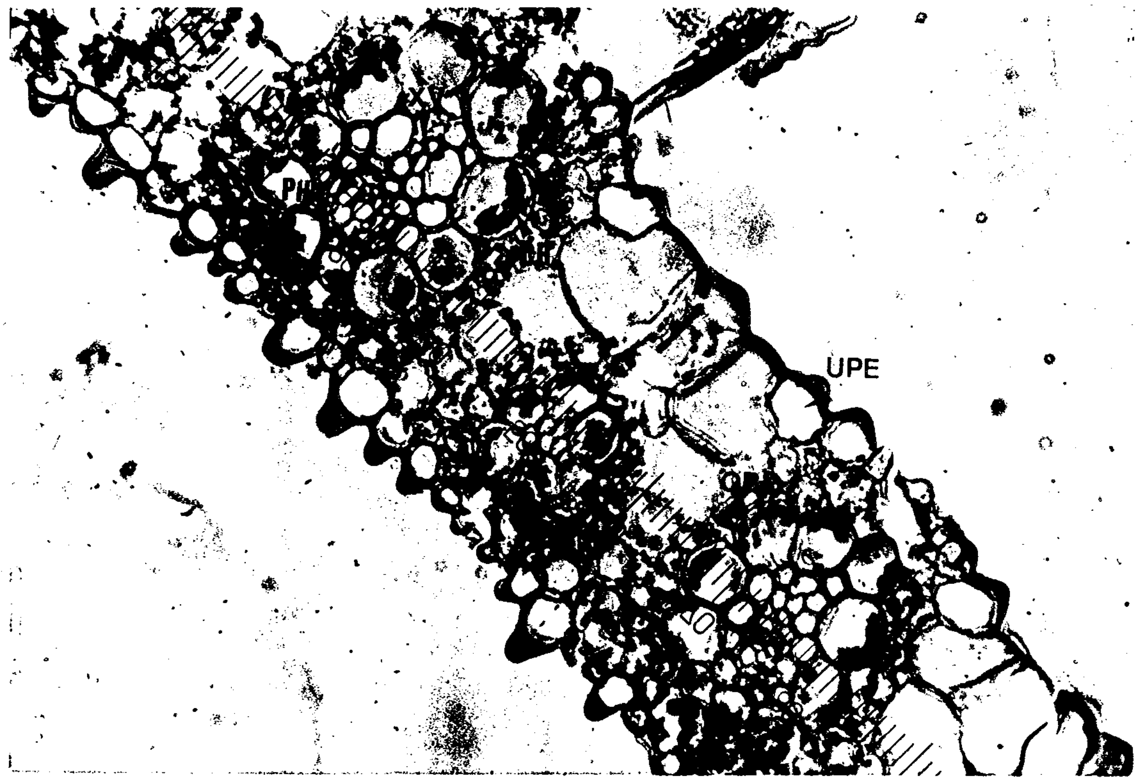


Plate D. Transverse section (20 x 2.5) of *I. cylindrica* leaf treated with glyphosate at 3 kg a.i. / ha., 3 days after treatment under non-water stress, in field conditions, showing well defined cells and no dark deposits in the vascular bundle cells as compared with stressed leaf.

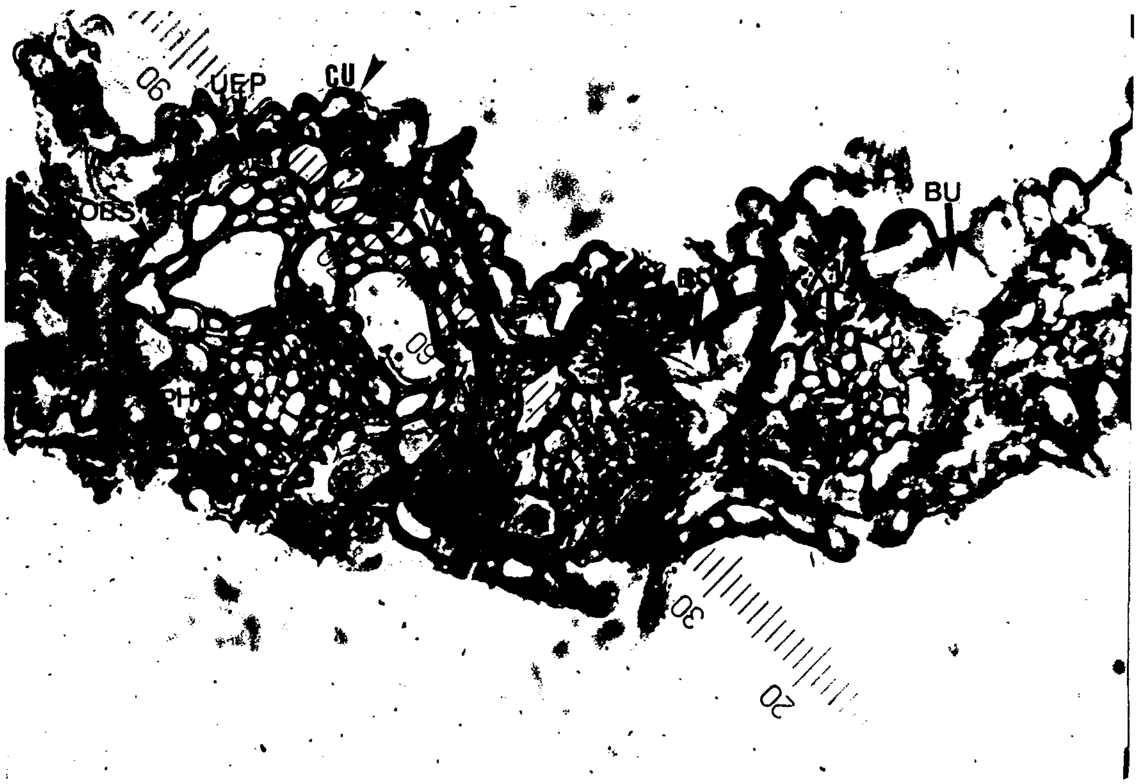


Plate E. Transverse section (20 x 2.5) of *I. cylindrica* leaf treated with glyphosate at 3 kg a.i. / ha , 5 days after treatment under water stress conditions, in glass house conditions, showing thickened cuticle, disorganized vascular bundles, and dark deposits in the phloem cells.

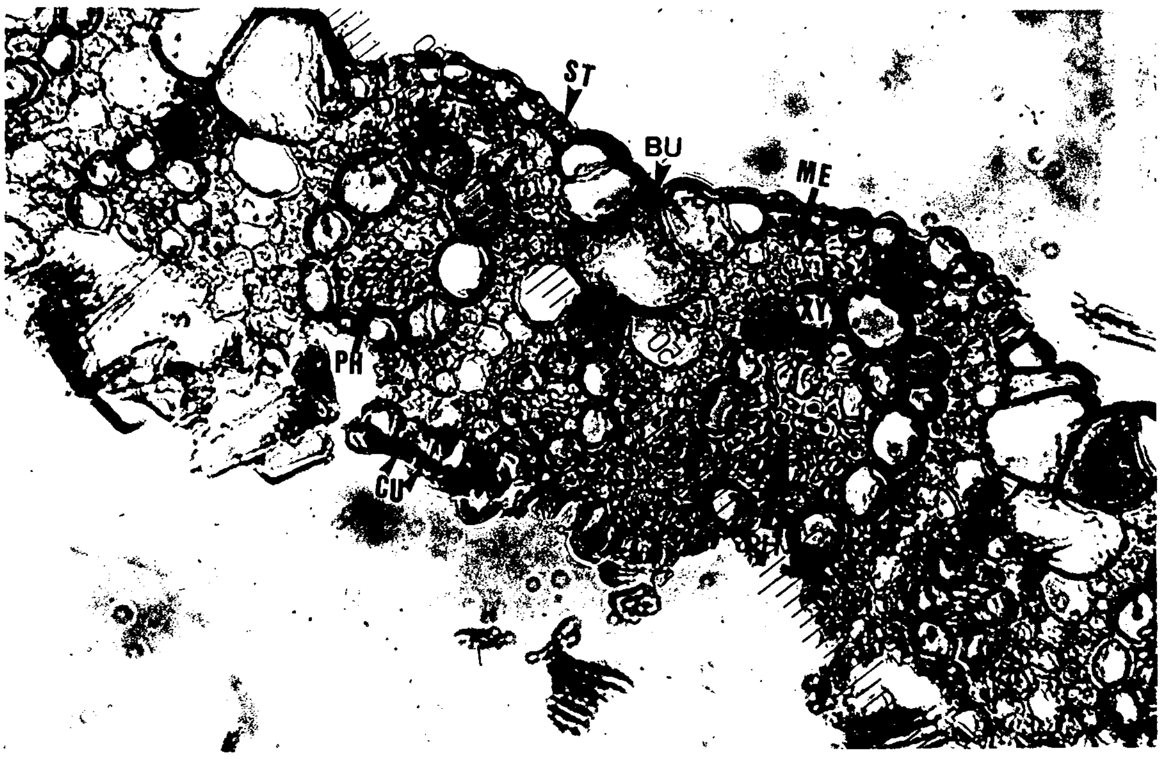


Plate F. Transverse section (20 x 2.5) of *I. cylindrica* leaf treated with glyphosate at 3 kg a.i. / ha., 5 days after treatment under water stress, in field conditions, showing dark deposits in vascular bundle, particularly in phloem cells.

Succession of Weed Communities on Abandoned Paddy Fields in Mountainous Regions in Japan

T. Ohkuro, K. Matsuo and M. Nemoto
National Institute of Agro-Environmental Sciences, Tsukuba, Ibaraki 305, Japan

Abstract. Successional patterns of weed communities on abandoned paddy fields were investigated in mountainous regions of heavy snows in central Japan. The 226 quadrats (2 m x 2 m) were situated on paddy fields and levee slopes differing in fallow duration (3, 12, 16 and 20 years lying fallow), and plant height and percent cover of each species were recorded. The samples were classified into two types based on dominant species by the first division of TWINSPAN (Hill 1979b), regardless of location or fallow period. *Miscanthus sinensis* community type occurred on dry sites of convex slopes, and *Phragmites australis* community type occurred on wet sites of concave slopes. The first axis of DCA ordination (Hill 1979a) was also interpreted as a gradient of soil moisture. In levee slopes, most stands were *M.sinensis* type, and were dominated by woody species except in those of 3 years fallow. In paddy field stands, only *M.sinensis* or *P.australis* have dominated for more than 20 years, and invasion of woody species seemed to be difficult because of litter accumulation. In some stands of *M.sinensis* type, however, woody species invaded the gaps among the clumps of *M.sinensis*. These results suggest that the succession of the abandoned paddy fields in the surveyed regions is affected by the soil moisture conditions related to micro-landform, the growth form of dominant species and the levee slope vegetation as a seed source.

Key words. abandoned paddy field, mountainous regions, soil moisture, succession, weed community.

Introduction

Abandoned paddy fields have expanded throughout Japan since the policy of reduction in rice production was carried out in 1970. Especially in mountainous regions, a labor shortage and poor land conditions together have accelerated the increase of abandoned fields (Nakajima 1993). Therefore, it is necessary to establish land conservation treatments based on ecological evaluation in such regions. The land conditions of paddy fields in mountainous regions are quite different from those in plain regions in scale of field unit, irrigation and drainage facility, surrounding vegetation and so forth. Matsumura *et al.* (1988) pointed out that successions of weed communities on abandoned paddy fields in mountainous regions were also influenced by such special land conditions. Few investigations, however, have been made while many studies have clarified the successional patterns in plain regions (e.g. Hakoyama *et al.* 1977; Anzai & Matsumoto 1988). Moreover, it is also expected that the vegetation of large-scale levee slopes developed with terrace paddy fields affect the processes of vegetation changes in paddy field sites.

The present study intends to clarify the successional patterns of weed communities on abandoned paddy fields and levee slopes in mountainous regions in central Japan, and to examine the appropriate treatments of those communities from a viewpoint of land conservation.

Study site and Methods

The investigation was conducted in Ohshima village, Niigata prefecture, central Japan (35° N, 138° E, 350-400 m above sea-level). Annual mean temperature and annual rainfall were 13 ℃ and 3,038 mm, respectively. The climate is characterized by heavy snowfall in winter. Mean maximum snowfall was 250 cm depth, and often reached more than 400 cm depth. The study site is also included in the land slide area. The bedrock was Neogene alternation of sandstone and mudstone. The forests around paddy fields were dominated by deciduous trees of Fagaceae such as *Quercus serrata* and *Q. mongolica* var. *grosseserrata*.

The paddy fields and levee slopes differing in fallow duration (3, 12, 16 and 20 years after fallow) were selected as survey sites. The paddy field was divided into two site, namely, the center and the edge. The latter was regarded as the site that was formed by the overhang of trees growing on levee slopes. The 226 quadrats (2 m x 2 m) in total were situated and plant height (H) and percent cover (C) of each species were recorded. Diameter at breast height of the woody plant that was more than 130 cm height was also measured. In the center of paddy field and the levee slope, height, number of culms, basal area of *Miscanthus sinensis* individuals were measured. Litter of *M. sinensis* was also clipped, dried and weighed.

Relative abundance (RA) of each species was calculated using: RD = H x C of the species / Σ H x C in each quadrat. RDs were transformed to the five class values as follows: RA<0.02; 1, 0.02-0.05; 2, 0.05-0.1; 3, 0.1-0.2; 4, 0.2<; 5. Two-way indicator species analysis (TWINSPAN; Hill 1979b) and detrended correspondence analysis (DCA; Hill 1979a) were applied using those class values to classify and ordinate the surveyed samples.

Results and Discussion

A total of 186 species appeared in the 226 quadrats. These samples were classified into the two types based on dominant species by the first division of TWINSPAN, regardless of location or fallow period, that is, the stands dominated by *M. sinensis,* and the stands dominated by *Phragmites australis* (Table 1). The former occurred on dry sites, and the latter on wet sites. The first axis of DCA ordination was also interpreted as a gradient of soil moisture. In general, successions in fallow paddy fields were discussed in relation to soil moisture (e.g. Hakoyama *et al.* 1977), as fallow paddy fields changed into ill-drained or well-drained fields according to drainage management (Anzai & Matsumoto 1988). The present study also confirm those previous studies. We also found that *M. sinensis* community type generally occurred on convex slopes and *P. australis* community type on concave slopes. This suggests that the soil moisture condition in the study area is closely related to micro-landform.

Matsumura *et al.* (1988) pointed out that the succession of abandoned paddy fields in mountainous regions differs from that in plain regions in that woody species established themselves in the early stage of the successional sere. In *M. sinensis*-community of three years fallow, woody plants such as *Weigela hortensis*, *Salix bakko*, *Acer palmatum* var. *matsumurae* invaded, which seems to correspond to the above-mentioned tendency. In the same community type of 12 years fallow, however, some woody species disappeared while the dominance ratio of *M. sinensis* increased. This suggests that the invasion of woody species in early stage does not always hasten the succession. In *M. sinensis* community, both the size of *M. sinensis* and the litter accumulation increased with the fallow duration. We also observed that *P. australis* showed the same tendency, although we didn't measured them. Litter accumulation inhibit invasions and establishments of seedlings, and cause local extinctions (Carson & Peterson 1990; Tilman 1993). Therefore, such litter effects might be one of the important factors in the long-term dominance of *M. sinensis* and *P. australis.*

Although *M. sinensis* community of 20 years fallow was still dominated by *M.sinensis*, the number of species including woody plants increased again. This community was also classified into other group than those of 3, 12 and 16 years fallow by the third division of TWINSPAN. On the contrary, in *P. australis* community of 20 years fallow, species composition and the number of species hardly changed. The invasion of tree seedlings into herbaceous communities may be partially controlled by gap formation in the grass canopy. (Harrison & Werner 1984; Goldberg & Gross 1988; Tang *et al.* 1989). Nemoto *et al.* (1993) also reported that grasslands dominated by *Dactylis glomerata* type which become clumped suffer from weed damages rather than those dominated by *Phalaris arundinacea* type which expand rhizome. As *M. sinensis* belongs to the former type, individuals of *M. sinensis* might have become clumped and formed heterogeneous spatial patterns including gaps. Consequently, seeds dispersed from levee slope vegetation and the surrounding forests and/or buried seeds may established themselves in some microsites.

In the levee slopes, most samples were *M. sinensis* community type. In contrast with paddy field,

Table 1. Mean abundance values of the species which appeared in more than ten quadrats in paddy fields and levee slopes differing in fallow duration. For the class values see text.

Stand groups divided by TWINSPAN	*M. sinensis* type											*P. australis* type							
site*	Center				Edge			Slope				Center				Edge			Slope
years after fallow	3	12	16	20	12	16	20	3	12	16	20	3	12	16	20	12	16	20	3
Number of quadrats	8	10	10	17	9	10	10	21	17	12	14	13	10	15	16	9	11	10	4
Viola verecunda	1	1	2	1	5	1	4	1	-	1	1	1	1	1	1	4	1	1	1
Miscanthus sinensis	5	5	5	5	5	5	3	5	5	5	4	1	2	-	-	-	-	-	1
Phragmites australis	1	-	1	3	-	-	-	4	1	-	-	5	5	5	5	5	5	5	5
Artemisia princeps	4	1	3	1	3	-	1	3	1	1	1	1	1	-	-	-	-	-	2
Boehmeria tricuspis	1	-	1	1	1	5	2	1	1	1	1	-	1	1	1	2	1	1	1
Equisetum arvense	1	-	2	1	-	1	-	1	-	1	-	1	1	1	1	1	1	1	1
Weigela hortensis	2	3	4	-	1	-	-	2	4	5	3	1	1	-	1	-	-	-	1
Petasites japonicus	1	-	1	1	2	1	1	1	1	1	-	1	1	-	1	2	1	-	1
Acer palmatum var. *matsumurae*	1	-	1	1	1	1	3	1	1	1	1	-	-	1	1	-	-	1	-
Oenanthe javanica	1	-	-	1	-	-	-	-	-	-	-	1	1	2	1	-	4	2	1
Hypericum erectum	1	-	-	-	1	-	1	1	1	1	1	1	1	-	-	2	1	-	1
Polygonum thunbergii	-	-	-	1	-	-	1	1	-	-	-	1	2	1	1	-	2	1	1
Stegnogramma pozoi ssp. *mollissima*	-	-	1	-	-	1	1	-	1	1	1	-	-	1	1	-	1	1	-
Lycopus ramosissimus var. *japonicus*	-	-	-	-	-	-	-	1	-	-	-	1	1	1	-	2	1	-	1
Arthraxon hispidus	1	-	1	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	1
Cimicifuga simplex	-	-	1	-	2	1	3	1	1	1	1	-	-	-	-	-	-	-	-
Wisteria floribunda	-	1	-	1	-	-	-	1	1	1	1	-	-	-	1	-	-	-	1
Osmunda japonica	-	1	-	-	2	1	1	1	1	1	3	-	-	-	-	-	-	-	-
Houttuynia cordata	-	-	-	1	1	1	-	1	1	-	1	-	1	-	1	-	-	2	2
Plectranthus trichocarpus	-	-	2	-	-	4	4	-	-	1	1	-	-	1	-	1	1	2	-
Impatiens textori	-	-	1	1	-	-	1	1	-	1	-	-	-	1	1	-	4	1	-
Arisaema japonicum	-	-	1	1	-	-	1	-	1	1	1	-	-	1	-	-	-	-	-
Parabenzoin praecox	-	1	-	1	-	1	3	-	1	1	1	-	-	-	-	-	-	-	-
Thelypteris palustris	1	-	1	1	-	-	-	2	-	-	1	-	-	1	1	-	1	1	1
Geranium thunbergii	1	-	1	-	-	1	-	1	-	1	-	-	-	1	-	-	-	-	1
Cardamine flexuosa	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	1	1	1	-
Scirpus hotarui	3	-	-	-	-	-	-	1	-	-	-	4	3	1	-	-	-	-	2
Vitis coignetiae	-	-	1	-	-	1	-	1	1	1	1	-	1	-	-	-	1	1	-
Pteridium aquilinum var. *latiusculum*	-	2	1	-	-	-	1	1	3	-	1	-	-	-	-	-	-	-	1
Dioscorea tokoro	-	-	-	1	1	1	1	-	1	1	1	-	-	-	-	-	1	1	-
Hydrangea macrophylla var. *megacarpa*	-	-	-	-	-	4	1	-	-	1	1	-	-	-	-	-	-	2	-
Viola kusanoana	-	-	1	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
Carex dispalata	1	-	-	-	-	-	-	-	-	-	-	1	3	1	-	-	4	-	-
Pueraria lobata	1	-	-	-	-	-	-	1	1	-	4	-	-	-	-	-	-	-	-
Ampelopsis brevipedunculata	-	-	-	1	1	-	1	-	-	1	1	-	-	-	1	1	1	1	-
Rubus palmatus	1	1	-	1	2	-	2	-	2	-	1	-	-	-	-	-	-	-	-
Amphicarpaea trisperma	-	-	-	-	-	1	1	1	1	1	1	-	-	-	-	-	-	-	-
Athyrium niponicum	-	-	1	-	1	1	1	1	1	1	1	-	-	1	-	-	-	-	-
Aralia cordata	-	-	1	1	-	1	1	1	-	4	2	-	-	-	-	-	-	-	-
Morus bombycis	-	-	-	-	-	-	1	1	3	3	3	-	-	-	1	-	-	-	-
Struthiopteris niponica	-	-	-	-	-	-	1	1	1	1	1	-	-	-	-	-	-	-	-
Carex lanceolata	-	-	-	-	1	1	-	-	1	1	1	-	-	-	-	-	-	-	-
Clethra barbinervis	-	-	-	-	1	-	1	-	1	3	5	-	-	-	-	-	-	-	-
Kalimeris pinnatifida	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	1
Ixeris dentata	1	-	1	1	-	-	-	1	1	-	-	1	-	-	-	-	-	-	1
Hydrocotyle ramiflora	1	-	-	-	-	-	-	1	1	1	-	1	1	-	-	-	-	-	1
Helianthus tuberosus	1	1	-	-	2	-	-	1	-	-	-	-	1	1	-	1	-	-	1
Stachyurus praecox	-	-	-	3	-	-	1	-	2	-	2	-	-	-	1	-	-	-	-
Polygonum cuspidatum	-	1	2	1	-	-	-	-	1	-	1	-	1	-	-	-	-	-	-
Akebia trifoliata	-	-	-	-	-	-	1	-	2	-	1	-	-	-	-	-	-	-	-
Viola brevistipulata	-	-	-	1	1	1	1	-	-	1	1	-	-	-	-	-	-	-	-
Salix bakko	1	-	-	-	-	-	-	1	2	1	1	-	-	-	-	1	-	1	-
Gentiana triflora var. *japonica*	1	-	-	-	-	-	1	1	-	1	-	-	-	-	-	1	-	-	-
Typha latifolia	-	-	-	-	-	-	-	-	-	-	-	5	4	-	-	-	-	-	-
Eupatorium lindleyanum	1	1	-	-	-	-	-	-	1	1	-	-	1	-	1	1	-	-	-
Athrium japonicum	-	-	-	-	-	-	-	1	1	1	-	-	1	-	-	-	-	-	-
Athyrium vidalii	-	-	-	1	1	-	-	-	-	1	1	-	-	1	1	1	1	-	-
Erigeron annuus	1	-	-	-	-	-	-	1	-	-	-	1	-	1	-	-	-	-	-
Heloniopsis orentalis	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
Dioscorea japonica	-	-	-	-	-	-	-	1	1	1	1	-	-	-	-	-	-	-	-
Humulus lupulus var. *cordifolius*	-	-	1	1	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-
Rubus parvifolius	-	-	1	1	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-
Lactuca raddeana var. *elata*	-	-	-	-	-	-	2	1	1	1	-	-	-	-	-	-	-	-	-

* Center: center of paddy field, Edge: edge of paddy field, Slope: levee slope.

however, those were dominated by woody plants of more than 300 cm height, except in the stand of 3 years fallow which was still dominated by *M. sinensis*. This finding suggests that the vegetation of the levee slope affects that of the paddy field in its seed source. The rapid establishment and the growth of woody plants were also effective in levee slope protection against the landslip and the soil erosion and so forth (Tsuyuzaki 1991). However, the discontinuance of the maintenance of levee slopes such as plastering and compaction increase the instability of the slopes (Chino *et al.* 1994; Mihara *et al.* 1994). Therefore, there is still some danger of the land failure, especially in stands dominated by herbaceous plants. Further studies on the relation between the occurrence of the land failure and the invasion of woody plants for a minute evaluation of the effect of the levee slope vegetation on the slope protection.

In conclusion, these results suggest that the succession of the abandoned paddy fields in the surveyed regions is affected by the soil moisture conditions related to micro-landform, the growth form of dominant species and the levee slope vegetation as a seed source.

References

Anzai, T. & N. Matsumoto, 1988. Emergence of weeds and changes in soil properties in fallow paddy fields. *Bull. Chiba Agric. Exp. Stn.* **29**: 93-104. (in Japanese with English summary)

Carson, W.P. & C.J. Peterson, 1990. The role of litter in an old-field community: impact of litter quantity in different seasons on plant species richness and abundance. *Oecologia* **85**: 8-13.

Chino, A., K. Kimura & M. Ito, 1994. Degradation of cultivated land and damage of the land caused by typhoon on the paddy field in steep sloping area. *Jour. JSIDRE* **62**: 295-300. (in Japanese)

Goldberg, D.E. & K.L. Gross, 1988. Disturbance regimes of midsuccessional old fields. *Ecology* **69**: 1677-1688.

Hakoyama, S., H. Tanaka, W. Agata & T. Takeda, 1977. Studies on weed vegetation in non-cultivated paddy fields, I. The vegetation of non-cultivated paddy fields in the north-western parts of Fukuoka prefecture. *Japan. Jour. Crop Sci.* **46**: 219-227. (in Japanese with English summary)

Harrison, J.S. & P.A. Werner, 1984. Colonization by oak seedlings into a heterogeneous successional habitat. *Can. J. Bot.* **62**: 559-563.

Hill, H.O., 1979a. *DECORANA- A FORTRAN program for detrended correspondence analysis and reciprocal averaging*. Cornell University Press, Ithaca, New York.

Hill, H.O., 1979b. *TWINSPAN- A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes*. Cornell University Press, Ithaca, New York.

Matsumura, M., N. Nishimura & Y. Saijoh, 1988. Plant succession in paddy fields lying fallow in Hida mountainous regions, Gifu prefecture. *Jpn. J. Ecol.* **38**: 121-133. (in Japanese with English summary)

Mihara, M., R. Yasutomi & N. Aiba, 1994. Levee slope protection measures taking account of soil structural changes. *Jour. JSIDRE* **62**: 315-319. (in Japanese)

Nakajima, K., 1993. Prevention of farm land wasting and development of paddy farming at sloping region in semimountainous area. *Research Reports on Agricultural Development in the Hokuriku Area* **29**: 1-36. (in Japanese)

Nemoto, M., T. Ohkuro & J. Mitchley, 1993. Gap characteristics and growth form tactics of colonizing weeds in sown meadows. *Abstracts of XV International Botanical Congress*: pp45.

Tang, Y.H., I.Washitani, T. Tsuchiya, & H. Iwaki, 1989. Spatial heterogeneity of photosynthetic photon flux density in the canopy of *Miscanthus sinensis*. *Ecol. Res.* **4**: 339-349.

Tilman, D. 1993. Species richness of experimental productivity gradients:how important is colonization limitation?. *Ecology* **74**: 2179-2191.

Tsuyuzaki, S., 1991. Present condition and regeneration of ski ground vegetation in Hokkaido -Ski grounds which have received land modification-. *Jpn. J. Ecol.* **41**: 83-91. (in Japanese with English summary)

Factor governing the growth of *Hydrilla vercillata* with special reference to Malaysian water

Mashhor Mansor* and Norhana Ab.Malik
School of Biological Sciences,
Universiti Sains Malaysia, Penang, 11800,
Malaysia

Abstract

Hydrilla verticillata is rated as the most noxiuos submerged aquatic weed in Malaysian water. Most of the waterways including canals and rivers particularly in urban areas are infested with the weed. Results from a laboratory experiment showed that there are several crucial factors such as nutrients, pH, light and water depth governing the massive growth of the weed. The mean growth rate was recorded as 0.64 g/day in hoagland solution. However, the growth was relatively slower in the same solution in the absence of phosphorus (0.46 g/day) and nitrogen (0.40 g/day). The plant could not survive in the solution without calcium and potassium. Good growth was recoded at pH 7 - 8 and light intensity of 1200 Lux. Red light and water depth help to stimulate the growth rate. Under suitable conditions, the plant can mature and produce flowers within 186 days from seeds.

Key words
Hydrilla verticillata, aquatic weed, nutrients, growth and survive.

Introduction

Since early 1960s Haller (1978) has indicated that *Hydrilla verticillata* has created problems in many waterways particularly in the southern parts of United States of America (USA). Swarbrick et al. (1980) added that *hydrilla* which is native to Australia has rapidly spread to Asia, Africa and southern part of Europe in the 1970s.
Gopal (1990) has included *Hydrilla verticillata* as one of the most noxious aquatic weeds in the south and south-east Asia. Soerjani (1976), Soerjani (1977), Pancho and Soerjani (1978), and Mansor (1988) emphasized the problems of *hydrilla* in south-east Asian countries. Most of the problems are mainly due to the

blocking of irrigation and drainage systems, interfering with hydroelectric scheme, and preventing fishing and recreation.

Apart from Norhana (1992), Mansor *et al.*(1988), Mansor and Baharuddin (1990), and Mansor (1991), the study on *Hydrilla verticillata* in Malaysia is quite limited. Therefore the main purpose of this study is to determine the important physico-chemical factors in governing the growth and also distribution of *hydrilla* in Malaysian freshwater ecosystem.

Materials and Methods

Field survey

A survey was conducted mainly on waterways from July 1990 to July 1994. Several irrigation and drainage canals, streams and rivers in Malaysia were visited and 218 sampling sites were established.

At the sampling sites, all the submerged aquatic plant species were recorded. *Hydrilla* for the laboratory experiment were harvested from Air Terjun River in Penang. At the site, several physico-chemical parameters including pH, conductivity and phosphate were recorded and analysed.

Effect of nutrient

More than 15 apical parts, each with a length of 5 cm were first washed with distilled water and exposed to 24 hrs light (1200 Lux). Five treatments were used and all the apical parts were then placed in 500ml conical flasks. For the first treatment, the apical parts were placed in hoagland solution (stock solution). The second treatment using hoagland solution minus nitrogen (-N) and the third treatment using hoagland solution minus phophorus (-P). For the fourth and fifth treatments, the same stock solution were used in the absence of potassium (-K) and calcium (-Ca) respectively. Each of the treatment was replicated three times and it was conducted for four weeks. Weekly readings were taken and the solutions were replaced.

Effect of pH

The 5 cm apical parts of the plants were placed in hoagland solution at a known pH. For the first treatment pH 4-5 was used. The second treatment was for pH 5-6. The third treatment using pH 6-7 and the fourth treatment using pH 7-8. The fifth treatment was pH 8-9. All the treatmnet were replicated thrice. Buffer solutions sulphuric acid and sodium hydroxide were used. Readings were taken every week over a period of four weeks.

Effect of light

For the experiment 5 cm of apical parts of *hydrilla* were embedded in the sandy substrate and placed in 7 litres of water (pH 7). Three treatments were used and were replicated three times. The first treatment was exposed to continous 24 hrs light (1200 lux) and the second treatment were under the shaded conditions (200 lux). The third treatment was 0 lux (total darkness). The experiment was run for four weeks and growth (length) readings were taken every week. For the effect of red, blue and green lights, the same type experiment was conducted by using the three different lights. Readings were taken every week over a period of four weeks.

Effect of depth

Three depths used for the experiment were 2 cm, 8 cm and 15 cm . The three depth treatments were replicated three times. Readings were taken every week over a period of four weeks.

Results and Discussion

From 218 sampling sites, high populations of *Hydrilla verticillata* were recorded at 100 sites. Perhaps more than 45 % of Malaysian waters are infested with *Hydrilla verticillata*. Mansor (1991) has singled out that *Hydrilla verticillata* is the most dominant submerged aquatic weed in Malaysia. There are several environmental factors which could substantiate the massive growth of this aquatic weeds. Undoubtedly the warm tropical climate is conducive for the good growth of the weed. Coupled with ample nutrient supply and available niche, the weed could propagate at a relatively fast rate.

In addition to sexual reproduction, the plant could produce by vegetative mean. Any parts break from the plant could grow successfully as an individual plant. Perhaps this is one of the reasons why apical parts of the plants were popularly used for most of the laboratory experiments. Two specialized reproductive structures, turion and tuber, enable the plant to produce and propagate without sexual mean. In Malaysia, it is fairly difficult to collect *hydrilla* seeds. Apparently, most of the *hydrilla* populations in Malaysia propagate vegetatively.

The *hydrilla* populations in Air Terjun River were healthy and roburst. They were found mainly on sandy substrates and the river was relatively clean with pH values ranged from 7.1 to 7.8. The soluble phosphate concentrations ranging from 0.018 mg/l to 0.033 mg/l, while the soluble ammonium concentration ranged from 0.039 to 0.176 mg/l. Most of the rivers and canals in urban areas are heavily infested with *Hydrilla verticillata*. However, *hydrilla* populations are seldom recorded in grossly polluted water.

Nutrients played a major role in the plant growth. Figure 1 shows *Hydrilla verticillata* grew well in hoagland solution (23.7 ± 5.14 cm). The mean growth rate

based on dry weight was recorded as 0.64 g/ day in hoagland solution. The plant could not survive in the solutions -Ca and -K. In -Ca and -K solutions the plants seemed to be dying after three weeks. After four weeks, the plant lengths reached 18.2 ± 4.0 cm for -P and 16.3 ± 7.0 cm for -N respectively. The final mean lengths for the five treatments were significantly difference (Anova, p=0.5). The growth was relatively slower in the same solution in the absence of P (0.46 g/day) and N (0.40 g/day) . Seemingly, it is quite obvious that the plants do not require phosphorus and nitrogen for their growth, however calcium and potassium seemed to be the most crucial elements. Sutton (1985) stated that the calcium in hydrilla leaves are high, and if the element is greatly reduced in a leaf, it could affect the proses of photosynthesis and finally retard the growth rate.
Figure 2 shows that over a period of four weeks, the highest growth length was recorded at pH 7-8 which reached a maximum of 17.3 ± 1.14 cm and the lowest growth length was at pH 11.9 ± 1.22 cm. The final mean lengths for the five treatments were significantly difference (Anova, p=0.5). Therefore it is not surprising that in Malaysia *hydrilla* are widely distributed in the waters range from 7-8.
Under 0 Lux, the plant could not survive for more than three weeks. The good plant growths were observed at 1200 Lux. Figure 3 shows a maximum length achieved was 10.7 ± 1.79 cm under red light over a period of four weeks. The mean lengths were significantly difference (Anova; p=0.50) for the four coloured lights. Sastroutomo (1980) stated that red and far-red irradation could promote germination of axillary turions, whilst blue and green lights markedly inhibited the germination. Therefore it is fair to conclude that light intensity, duration and colour have played significant roles in the plant growth and germination.
The fastest length growth was recorded from the depth of 15 cm and the growth was relatively slow at 2 cm depth (figure 4). There were a significant difference (Anova; p=0.5) between the three final readings. Perhaps water level played a major role in this submerged plant growth. The higher the water levels, the longer the length. Generally, this phenomenon occasionally creates two ecotypes, deep and shallow water populations. Sometimes the morphological characteristics of these two populations are relatively different. Langeland et al. (1992) stated that *Hydrilla* is highly polymorphic and the leaf and stem morphology can differ between populations. They also encountered male populations in Malaysian water.
In conclusion, *Hydrilla verticillata* is the most noxious submerged aquatic weeds in Malaysia. The population grew well in a nutrient rich waters with pH values ranged from pH 7-8. It grew well under 1200 Lux and require red light condition. Deeper waters seemed to be better for

its growth. Finally in the laboratory, it took 186 days to flower.

Acknowledgment

We wish to thank Mr. Ganesh for helping us to complete the experiment. The Universiti Sains Malaysia (USM) is gratefully acknowledged for providing the facilities and also part of the research funds (R&D)

References

Gopal,B. (1990). Aquatic weed problems and management in Asia. In Aquatic Weeds- The Ecology and Management of Nuisance Aquatic Vegetation , edt. Pieterse, A.H. and Murphy, K.J. Oxford Science Pub. 318-340 pp.

Haller,W.T.(1978). Hydrilla. IFAS University of Florida. 13p

Langeland,K.A.,Shilling,D.G.,Carter,J.L.,Laroche,F.B., Steward,K.K. and Madiera,P.T.(1992). Chromosome morphology and number in various populations of *Hydrilla verticillata* (L.f.)Royle. Aquatic Botany, 42. 253-263.

Mansor,M., Joyce,J. and Thayer,D.(1988). Effect of Aquathol K on Hydrilla verticillata. PERTANIKA Vol 11. 191-194 pp.

Mansor,M. and Baharuddin,M.H.(1990). Photosynthesis of Hydrilla verticillata. In; Transaksi Fisiologi Tumbuhan Malaysia. edt. Hamid L. et al. 185-190 pp

Mansor,M. (1990). Noxious submerged weeds of Peninsular Malaysia. In: Vegetation management strategy for sustainable development , edt. Swarbrick, J.T. et al. Pub. Asian Pacific Weed Sc. Society. 143-149 pp.

Norhana,A.M.(1992). Kajian Biologi Rumpai Akuatik *Hydrilla verticillata*. B.Sc. thesis USM. 92 p.

Pancho,J.V. and Soerjani,M.(1978). Aquatic weeds of southeast Asia. National Pub. Corp., Quezon City, Philippines.130 p.

Sastroutomo, S.S.(1980). Dormancy and Germination in Axillary Turions of Hydrilla verticillata. Bot.Mag.Tokyo 93. 265-273 pp.

Soerjani, M. (1976). Aquatic weed problems in Indonesia, with special reference to the construction of man-made lakes. In Aquatic weeds in South East Asia, ed. Varshney,C.K. and Rzoska,J.W.Junk,The Hague.67-78 pp

Soerjani,M. (1977). Aquatic Weeds of Southeast Asia- A systematic account of Common Southeast Asian Aquatic Weeds. UPLB-BIOTROP.59 p.

Sutton, D.L. (1985). Culture of hydrilla (Hydrilla verticillata) in sand root media amended with three fertilizer. Weed Science, 34. 34-39.

Swarbrick,J.T.,Finlayson, C.M. and Cauldwell,A.J. (1982). The biology and control of Hydrilla verticillata (L.f.)Royle. Biotrop special pub. no 16.

Figure 1; The effect of nutrients on the growth of hydrilla

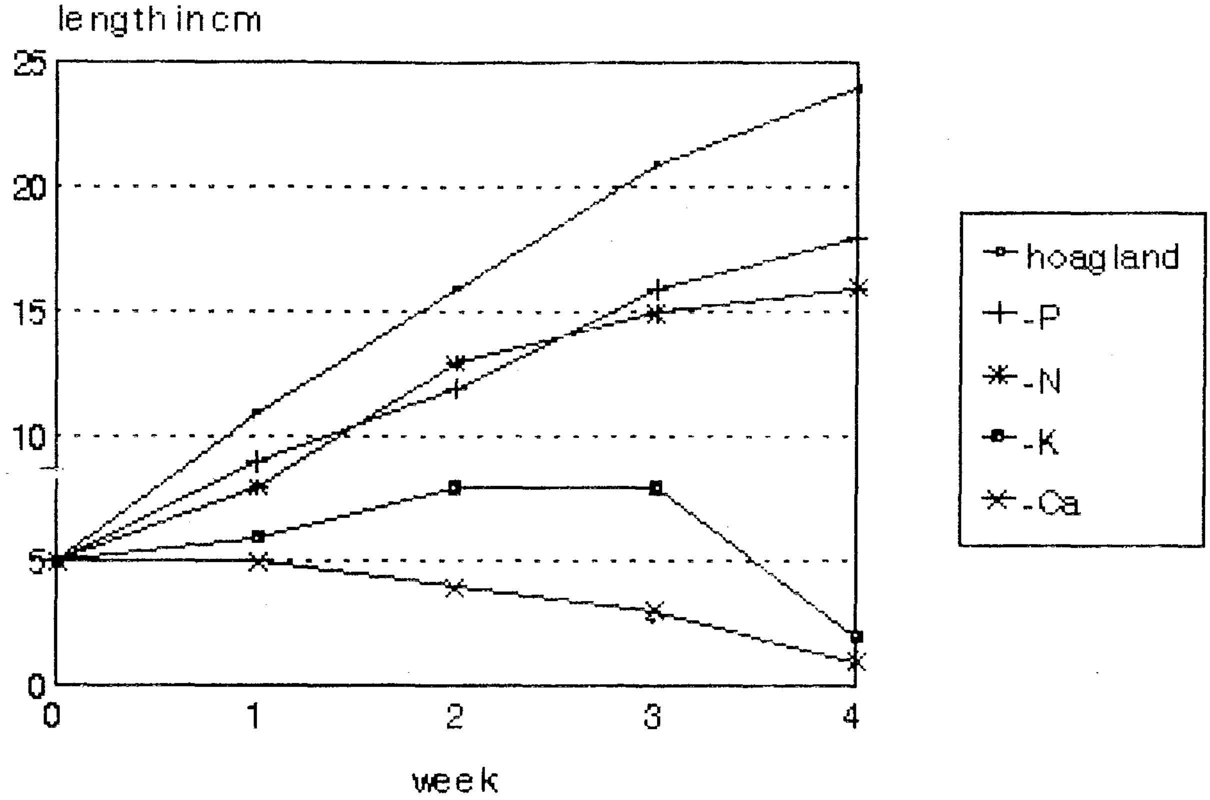


Figure 2; The effect of pH on the growth of hydrilla

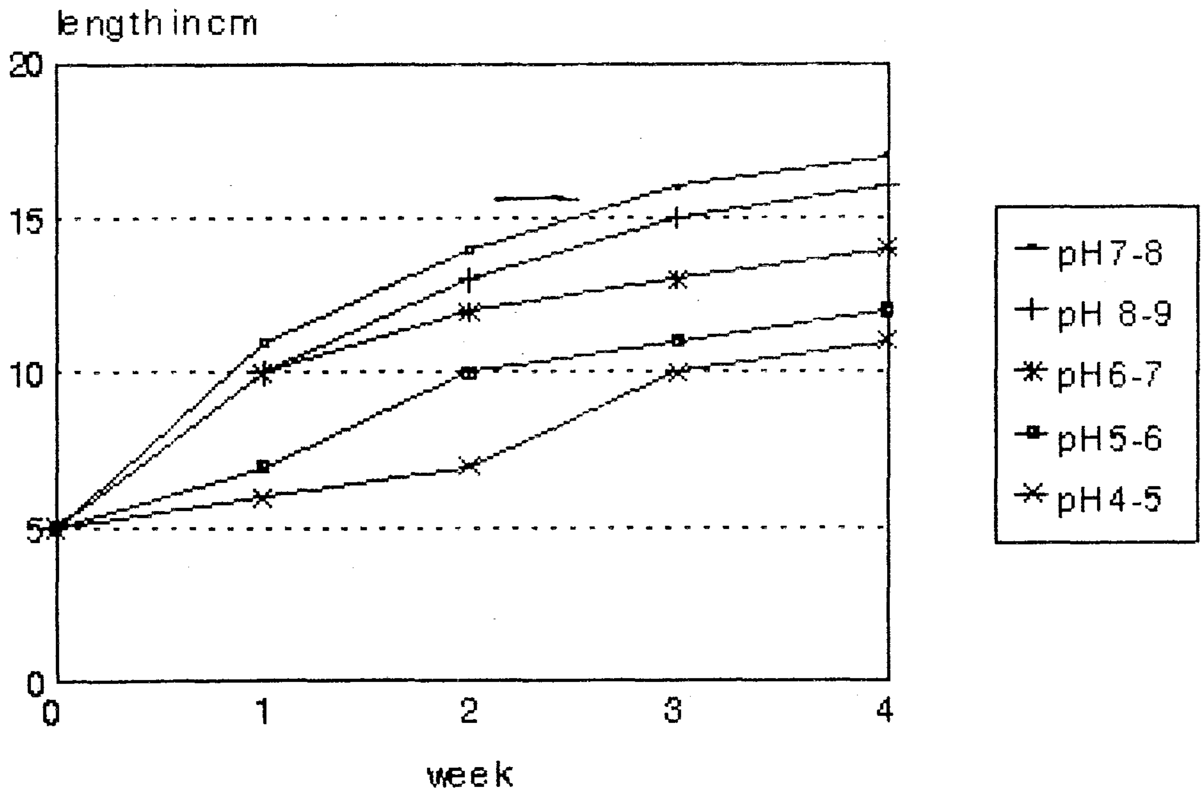


Figure 3; The effect of light colouration on hydrilla

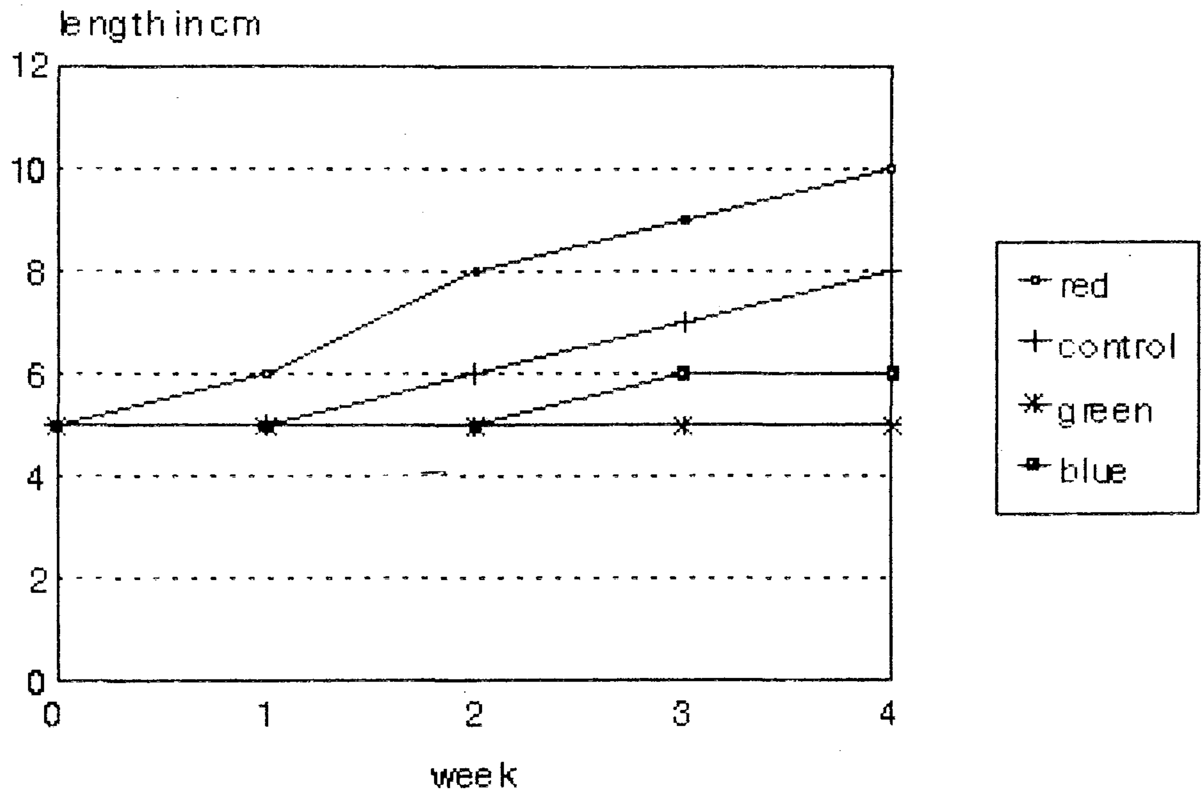
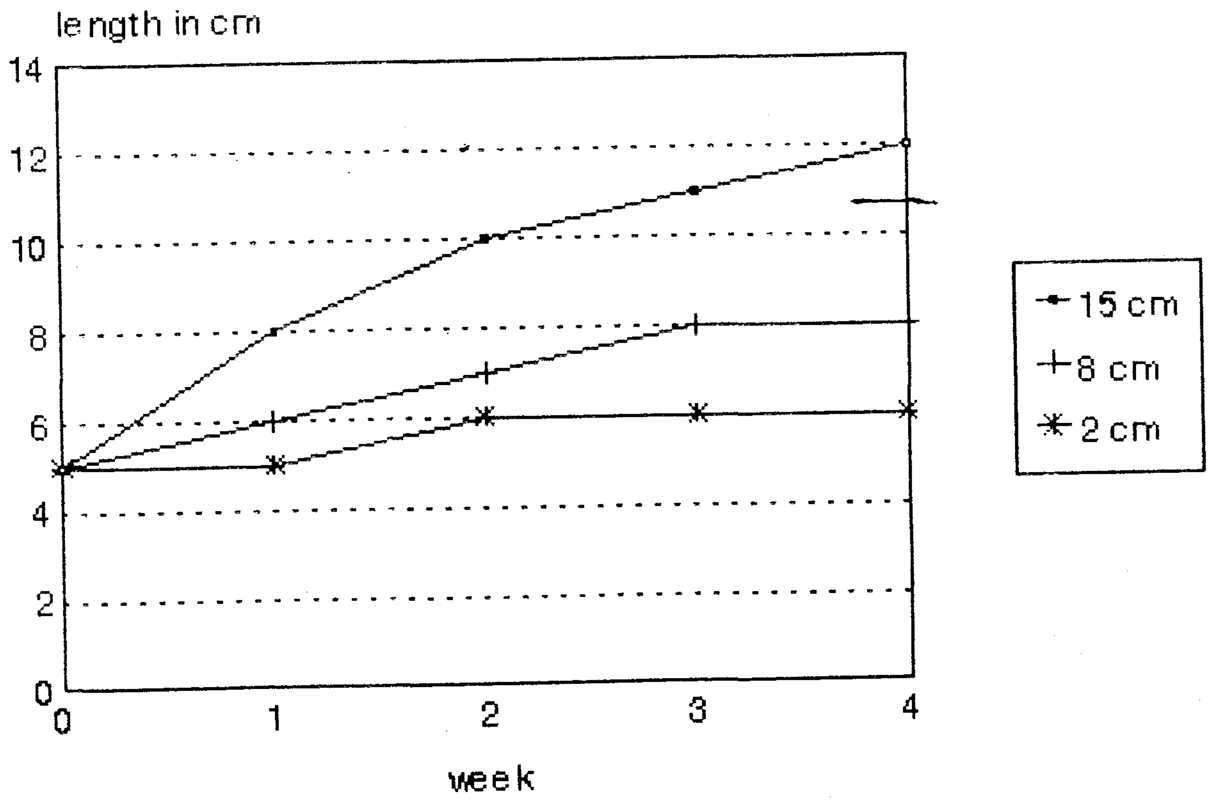


Figure 4; The effect of depths on the growth of hydrilla



Control of Myrica faya in Hawaii

P. Motooka*[1], G. Nagai[2], K. Onuma[3], M. DuPonte[4], and W. Shishido[3]

[1]University of Hawaii, P.O. Box 208, Kealakekua, Hawaii, 96750, U.S.A.; [2]Hawaii Department of Agriculture, Hoolehua; [3]Hawaii Department of Agriculture, Hilo; and [4]Universty of Hawaii, Hilo.

Absract. In 1979 the Hawaii Department of Agriculture reported that fayatree (Myrica faya) infested 18,000 ha of forests and pastures in Hawaii (4). Since then fayatree infestations have expanded and there is currently no practical alternative to herbicides for controlling them. Field trials were conducted to develop herbicidal control measures to help foresters and ranchers contain fayatree infestations. Glyphosate or picloram applied to cut-surfaces of large trees were more effective than dicamba or triclopyr, whether the cuts to the trunks were made at 20 cm intervals or end-to-end in continuous rings. Picloram applied to spaced cuts was effective on large trees whether the cuts were made at waist height or near ground level. Foliar applications of triclopyr or 2,4-D were more effective than dicamba or metsulfuron. Basal bark applications of 2,4-D and triclopyr caused severe injury to fayatree saplings but triclopyr killed more plants. In both foliar and basal bark applications, good coverage was difficult to achieve because of the dense canopy of fayatree saplings which reached ground level. Thus repeat treatments would be necessary to kill plants that survive.
Key words. Basal bark, cut-surface, foliar application, herbicidal control, Myrica faya.

Introduction

Variously called firebush, firetree, fayabush, and fayatree in Hawaii, Myrica faya was introduced into Hawaii around 1900 by Portugese immigrants (2). Indigenous to the Azores, Madeira, and Canary Islands, fayatree is a non-leguminous nitrogen-fixer (2). As late as 1940, shortly before the plant was recognized as a noxious weed, the then-territorial government of Hawaii had fayatree planted in conservation projects (2). Also spread by birds, fayatree infested 18,000 ha by 1979 (4), the last time an official survey of noxious weeds was made in Hawaii. It has spread further since then, most notably in the Hawaii Volcanoes National Park and adjacent areas on the island of Hawaii (2). With biocontrol methods not yet developed, the State of Hawaii Department of Agriculture (DOA) now maintains a chemical control program to assist landowners in controlling the spread of fayatree infestatons. The DOA effort initially was aimed at killing large trees which were planted in early conservation projects. Their procedure was to apply diluted picloram (Tordon 22K, 240 g a.e./l) into dozens of machete cuts made around the base of fayatree trunks. Although this method was effective, the unilateral use of picloram raised concern about the lack of alternative chemicals should the registration of picloram products be cancelled. In addition, the large number of cuts made per tree posed a high risk for worker injuries, especially as the workers tired. Finally, to contain the spread of fayatree, there was a need to develop control measures for saplings in pastures and forests. Because of the dense canopy that reached to ground level, it was impractical to employ the cut-surface method on saplings because too much labor would have been required to remove the low branches to gain access to the basal stem. Furthermore, soil-applied dicamba (Banvel, 480 g a.e./l), hexazinone (Velpar L, 240 g a.i./l), picloram, and tebuthiuron (Spike 20P, 20% a.i.) were ineffective on trees and saplings(1). Trials were conducted at Paauilo and Volcano on the island of Hawaii, two of the most severely infested areas of the state, to develop efficient procedures for the control of both trees and saplings of fayatree.

Objectives

The objectives of this project were to evaluate:

1. cut-surface applications of dicamba, glyphosate (Roundup, 360 g a.e./l), picloram, and triclopyr amine (Redeem, 360g a.e./l) to spaced and continuous ring cuts on large trees.
2. the application of picloram to spaced cuts made at near ground level (low basal) and at waist height on large trees to determine if stooping by workers to make the cuts and to apply the herbicide can be eliminated.
3. foliar applied 2,4-D (Esteron 99, 456 g a.e./l), dicamba, glyphosate, metsulfuron (Ally, 60% a.i.), picloram, and triclopyr amine and ester (Remedy, 480 g a.e./l) on fayatree saplings.
4. basal bark applications of 2,4-D and triclopyr ester to control fayatree saplings.

Materials and Methods

Cut-surface applications.

Two cut-surface application trials were conducted at Pauuilo on large trees (ca 70 cm dbh). In the first trial, to evaluate different herbicides and to determine if the number of cuts prescribed by the DOA procedure may be reduced, herbicides were applied to cuts spaced 20 cm apart and to cuts made end-to-end in a continous ring around the trunk base near ground level. The cuts were made with a machete at a 45° angle and 1 ml of undiluted 2,4-D, dicamba, glyphosate, picloram, or triclopyr was applied to each cut with a household spray bottle adjusted to deliver a straight stream. Thus the trees with continuous ring cuts received twice the herbicide dose as did the trees with spaced cuts. There were ten replicates, completely randomized. In all the trials reported herein, a visual injury rating system scoring between 0 for no injury to 100 for plant kill was utilized. Statistical analyses were made on arcsin transformed data which were retransformed for presentation. In the second cut-surface trial, to determine if stooping by applicators to make low basal cuts and herbicide applications can be eliminated, applications of picloram was evaluated when applied to spaced cuts made on the tree trunk near ground level and to spaced cuts cuts made at waist height. There were ten replicates per treatment, completely randomized. Evaluations were made at 16 months after treatment.

Foliar applications.

Two foliar application trials were conducted on ca 2 m tall fayatree saplings at Volcano. The low volume drizzle application procedure,wherein the herbicide was applied through a 0.5 mm orifice disc under CO_2 of 1.44 kP and which produced a fine straight stream which was distibuted by waving the sprayer wand (3), was used in the first trial. Application at 14 l/ha was made from two opposite directions to ensure adequate coverage of the plant canopy. The treatments were: 2,4-D at 2 kg a.e./ha, dicamba at 2 kg a.e./ha, picloram at 0.5 kg a.e./ha, and triclopyr amine at 0.5 kg a.e./ha. In the second trial, also at Volcano, 2,4-D at 2 kg a.e./ha, dicamba at 2 kg a.e./ha, metsulfuron at 30 g a.i./ha and triclopyr ester at 1 kg a.e./ha were applied through a 11002 low pressure flat fan nozzle under CO_2 pressure of 1.44 kP, delivering a spray volume rate of 211 l/ha. There were ten replicates per treatment in each trial, completely randomized. Evaluation was made at six months after treatment.

Basal bark applications.
A basal bark application trial was conducted on 5 m tall saplings at Volcano. A diesel oil check and 2,4-D and triclopyr, each diluted to 2 % of the commercial product in diesel were applied by inserting a spray wand into the fayatree canopy and spraying completely around the basal stem between ground level up to 50 cm high. A sprayer pressurized to 1.44 kP with CO_2 was used with a hollow cone nozzle. There were ten replicates, completely randomized. The plants were evaluated six months after treatment.

Results and Discussion

Cut-surface treatments.
In the first cut-surface trial, glyphosate and picloram were equally effective on large fayatree and more effective than dicamba and triclopyr. Furthermore, applications to spaced cuts were as effective as applications to continuous ring cuts (Table 1).

Table 1. Control of fayatree by application of herbicides to spaced and continuous ring cut-surfaces at 16 months after treatment.

Herbicide	Injury Rating[1]		Kill
	(20 cm Spacing)	(Continuous Ring)	(%)
Dicamba	74	67	10
Glyphosate	94	96	67
Picloram	99	99	80
Triclopyr amine	42	65	0

[1]F test for herbicides significant at p=0.01, F test for cut intervals non-significant.

In the second cut-surface trial, there was no significant difference between application of picloram to low basal cuts and to cuts at waist height (Table 2). Thus workers would not have to stoop to make cuts and to apply picloram thereby eliminating much of the labor of the standard DOA practice. The results of both of these trials suggest that by reducing the number of cuts per tree and making the cuts at waist height, efficiency and safety can be increased over the standard DOA practice. Whether glyphosate is efficacious when applied to waist height cuts was not determined but, given its efficacy in low basal cut treatments, it probably would do as well as picloram.

Foliar trials.
Drizzle application, which produces large, sparsely distributed Table

Table 2. Effect of height of cut-surface treatments with picloram on fayatree control at 16 months after treatment.

Height of Cuts	Herbicide	Injury Rating	Kill
			(%)
Ground level	None	0	0
Ground level	Picloram	99	87
Waist high	None	0	0
Waist high	Picloram	100	100

droplets (3), apparently did not provide adequate coverage for the dense foliar canopy of fayatree. Glyphosate and 2,4-D produced more serious injury than dicamba, picloram, or triclopyr. However, picloram and triclopyr were applied at rates a fourth that of dicamba and 2,4-D (Table 3). In the second foliar trial, in which herbicides were applied by conventional spraying, 2,4-D and triclopyr were effective and dicamba and metsulfuron were ineffective (Table 4). Despite severe injury caused by the most effective treatments, the rates of kill were poor which suggested that repeat applications would be necessary . High volume spraying may provide better results and would be practical in pastures but not in forests where transport of large equipment and large volumes of water would be a problem and where endangered plant species may be exposed to herbicide drift.

Table 3. Control of fayatree by drizzle application of herbicides at two months after treatment.

Herbicide	Rate	Injury Rating[1]
	(kg/ha)	
Check	0	3
2,4-D	2	39ab
Dicamba	2	6cd
Glyphosate	3	54a
Picloram	0.5	22bc
Triclopyr amine	0.5	31bc

[1]Means followed by different letters significantly different by LSD test at p=0.05.

Basal bark application.

Both 2,4-D and triclopyr applied in diesel to the base of fayatree saplings caused severe injury to the target plants (Table 5). Although the difference of the means of the injury ratings between these two treatments were not statistically significant, the triclopyr treatment killed 40% of treated plants whereas the 2,4-D treatment killed none. The dense canopy of fayatree saplings blocked the applicator's view of the stem area to be sprayed and hindered the movement of the spray wand. This probably resulted in inadequate spray coverage of the basal stem and reduced efficacy of the treatment. However, defoliation caused by the treatment should allow better coverage in followup treatments.

Table 4. Fayatree control by foliar applicaton of herbicides at six months after treatment.

Treatment	Injury Rating[1]	Kill
		(%)
Check	0	0
2,4-D, 2 kg a.e./ha	80a	10
Dicamba, 2 a.e./ha	25b	0
Metsulfuron, 30 a.i./ha	40b	0
Triclopyr, 1 kg a.e./ha	75a	10

[1]Means followed by different letters significantly different by LSD test at p=0.05.

Table 5. Fayatree control by basal bark application of herbicides at six months after treatment.

Treatment	Injury Rating[1]	Kill
		(%)
Diesel Check	12b	0
2,4-D, 2%	54a	0
Triclopyr, 2%	86a	40

[1]Means followed by different letters significantly different by t test at p=0.05.

Conclusions

Large fayatrees were controlled by applications of picloram and glyphosate to spaced and continuous ring basal cuts to the trunk. Cut-surface applications of picloram was as effective with cuts made at waist height as at ground level, thus indicating that fewer cuts than the DOA practice and the elimination of stooping by applicators would be practical. Conventional foliar applications of 2,4-D and triclopyr were effective in suppressing fayatree saplings. Although the saplings survived the application, the severity of the plant response suggested that repeat applications would provide adequate kill. Basal bark applications of triclopyr on saplings was more effective than 2,4-D, but as with foliar treatments, repeat applications would be necessary because the dense foliar canopy probably prevented adequate coverage of the basal stem.

Acknowledgment: The DowElanco and DuPont de Nemours companies supplied some of the herbicides used in this study and the State of Hawaii Department of Transportation and the United States Highway Administration under contract 26513 to the University of Hawaii College of Tropical Agriculture and Human Resources supported parts of this study.

References

1. Hawaii Institute for Tropical Agriculture and Human Resources. 1988. Summaries of herbicide trials for pasture, range, forage crops and non-cropland weed control 1986-1987. Brief 74. Univ. Hawaii Coll. Trop. Agric. Human Resour. Honolulu. 13+vi p.

2. Little, E.L. Jr. and R.G. Skolmen. 1989. Common Forest Trees of Hawaii (Native and Introduced). Agriculture Handbook 679. U.S. Dept. Agric. Fores. Svc. Washington, D.C. p. 92.

3. Motooka, P., G. Nagai, and L. Ching. 1983. The Uyeda "magic wand" method of herbicide application. Proc. Ninth Asian Pacific Weed Sci. Conf. Suppl. Vol. p. 550-553. Nov. 28-Dec. 2. Manila.

4. Tagawa, T. 1979. Foreign Noxious Weed Survey. State of Hawaii Dept. Agric. and U.S. Dept. Agric. Honolulu. 130p. (Mimeo.)

Weed Species Diversity and Its Conservation Value

M. Nemoto[1)] and J. Mitchley[2)]

1)National Institute of Agro-Environmental Sciences, Tsukuba, Ibaraki 305 Japan
2)Wye College, University of London, Wye, Ashford, Kent TN25 5AH, UK

Abstract. Agro-ecosystems producing the crops for humankind usually include various kind of invading weed species. Weed species in grassland of agro-ecosystem can be divided into two types from their relative plant height, tall-growing weeds and short-growing weeds. The former have the potential to depress the growth and yield of forage plants. The latter usually grow in the bare spaces between the forage plants. Invading weedy plants extend their above-ground organs through their growth form tactics (GFT) and the GFT of weeds can be divided into position fortifying tactics (PFT) and position extending tactics (PET). The increase in biomass of tall-growing PFT weeds clearly promotes the degradation of grassland vegetation, and therefore, they must be controlled. However, the short-growing PET weeds do not have the same impact as tall-growing PFT weed. When grassland vegetation is in a mature stage, an increase in species richness of short-growing PET weeds may be brought about by suitable management and enhance biodiversity and conservation value of the agro-ecosystem.

Key Words. agro-ecosystem, conservation, growth form, position extending, position fortifying, short-growing weed, species richness, tall-growing weed.

Introduction

Modern agricultural technology has dramatically increased crop production level by use of chemical fertilizers and pesticides, and by introducing new crop varieties which are adapted to this modern system. This system has also made possible reduced working hours in the field. On the other hand the excessive investment of these agricultural methods has revealed the negative side of the agro-ecosystem: the demise of the sustainable use of farmland, the decline in amenity of traditional rural landscapes, and loss of biodiversity.

The agro-ecosystem comprise the cultivated crop as target plant. Here "crop" means all kinds of plants which are used for the life of humankind. The system normally involves a weed as an uninvited guest. The agro-ecosystem comprises not only fields for crop production but their surroundings such as footpaths between rice fields, farm roads, embankment slopes in rural land. The objective of this paper is to describe the diversity of weed species in grasslands and their conservation value in the agro-ecosystem.

Weed species diversity

Weed's-eye view of interrelations in the agro-ecosystem

Human have long treated weeds in agro-ecosystem as pests in a broad sense which disturb and suppress the growth of crops. By contrast with this human viewpoint, what is the weed situation in the agro-ecosystem from the weed's eye view?

The effects of weed growth can be divided into those on crop production and those on already existing weed species. As shown in Table 1, four types of effects can be considered(Nemoto 1994). Effect 1. is that of depriving the cup of indispensable elements, light, water and nutrients. The vast majority of studies have the characteristics of weeds in terms of this effect. Effect 2. is the protective effects of weeds. For example, under the strict weather conditions in winter, the existence of weeds helps alleviate these conditions, resulting in a better crop growth than on bare ground (Niiyama & Numata 1969). Effect 3. includes that of preventing the invasion and colonization of harmful weeds by non-harmful weeds which cover all bare ground (Oki, Ishikawa & Ohmine 1995). Finally, Effect 4. is that of modifying micrometeorological characteristics like Effect 2., but in the case the effect is directed to newly invading harmful weeds and has a negative impact on agro-ecosystem conservation value.

Table 1. Weed's-eye view of interrelation in the agro-ecosystem

Weeds vs cultivated crops	Weeds vs weeds
1. Exploitation (–) 2. Protection (+)	3. Obstruction (+) 4. Protection (–)

+ Useful effects for the conservation of the agro-ecosystem
– Harmful effects for the conservation of the agro-ecosystem

Growth form diversity of weeds

The influence of weeds on the conservation of the agro-ecosystem can theoretically be divided between useful effects and harmful ones as above. In this section the characteristics of weeds are classified according to their growth form.

Growth form is shoot architecture based upon plant morphology. It reflects the environmental characteristics of the micro-habitat rather than Raunkiaer's life form (Gimingham 1951). The growth form of weedy plants shows a high degree of phenotypic plasticity. The growth form characteristics of weed plants can be divided into the vertical and horizontal components. The vertical component is determined by the potential plant height of weed species and controls interspecific competition (Grubb 1977, Grubb, Kelly & Mitchley 1982) and is greatly influenced by grassland managements such as mowing, grazing (Mitchley 1994). The horizontal component is determined by the growth form of the colonizing weed (Mitchley 1994) and the growth form tactics of dominant species in particular plays a vital role in determining species richness and community stability in grassland (Nemoto, Ohkuro & Mitchley 1993).

Weeds in sown grassland may be classified into two types according to plant height (Nemoto & Kanda 1976). One is the type of tall-growing weeds higher than, or the same height as the sown forage species. Annual species such as *Erigeron annuus* , *E. philadelphicus* , *Commelina communis* , *Digitalia ciliaris* and *Echinochloa crus-galli* and perennial species such as *Rumex obtusifolius, Miscanthus sinensis, Imperata cylindrica* and *Solidago altissima* are examples of tall-growing weeds.

The other is the type of short-growing weeds shorter than the sown species. Annual species such as *Stellaria alsine, S. media, Cerastium caespitosum, Sagina japonica* and perennials such as *Plantago asiatica, Zoysia japonica* and *Mazus miquelii* are examples of short-growing weeds. This type of weed is not damaged by the cutting height of 4 ～10cm above ground.

The influence of weeds of the tall-growing type on herbage differs from that of the short-growing weeds. In general, the former has a competitive relationship with herbage species and the latter has a cooperative relationship with them. Under usual management, the presence of short-growing weeds scarcely affects the growth of herbage, in contrast there may be a suppressing effect on the tall growing weeds (Nemoto & Numata 1979).

Growth form tactics of colonizing weeds

This classification of weed species takes account of relative plant height. On the whole, however, in sown grasslands there are few gaps which allow sufficient growth of invading weeds. The exploit action of space is also important and the growth form tactics (GFT) of colonizing weeds based on the phenotypic plasticity determine the exploitation of living space in grassland.

To persist as a member of a plant community the weed species must fulfil the following three conditions: 1) The seed which invades a gap germinates and the seedling establishes. 2) The seedling grows to reproductive stage without being outcompeted in the competition with the previously established neighbouring plant species. 3) The mature plant produces reproductive organs and fertile seed. From the standpoint of life history strategies, a number of studies on the mechanisms which contribute to the response of weed plant to physical environments have been carried out. However, phenotypic plasticity emphasizing the development stage of invading weeds has scarcely been analyzed to consider the influence of forage grasses adjacent to weed plants.

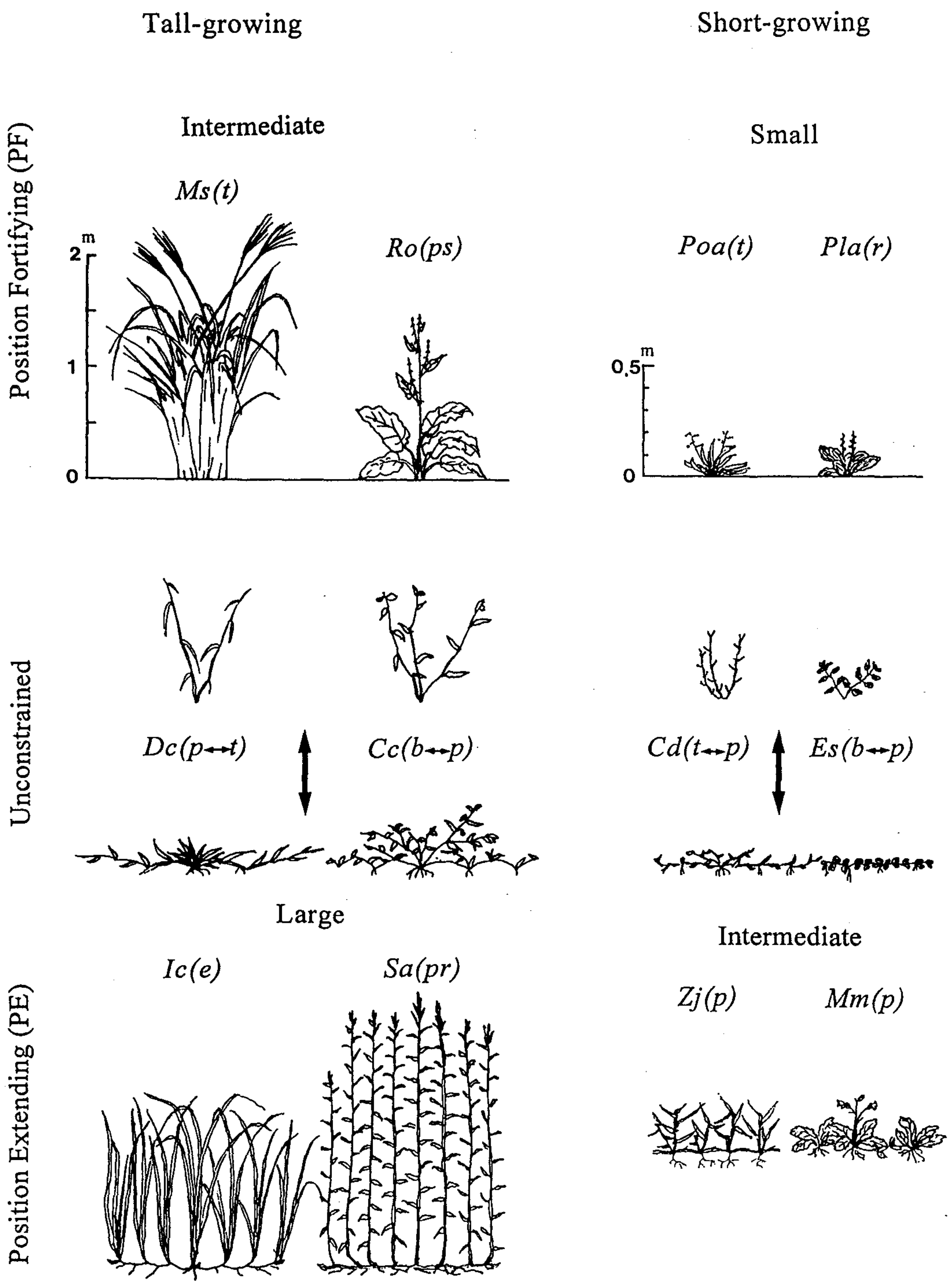


Fig.1. Diagrammatic illustration of growth form of weeds in sown grassland
note: *Ms:Miscanthus sinensis, Ro:Rumex obtusifolius, Poa:Poa annua, Pla:Plantago asiatica, Dc:Digitaria ciliaris, Cc:Commelina communis, Cd:Cynodon dactylon, Es:Euphorbia supina, Ic:Imperata cylindrica, Sa:Solidago altissima, Zj:Zoysia japonica, Mm:Mazus miquelii,*
(t)tussock form, (ps)pseudo-rosette form, (r)rosette form, (b)branched form, (p)procumbent form, (pr)partial-rosette form, (e)erect form

We define GFT as the way in which plant maintains and/or develops its living space by means of phenotypic plasticity during the period from establishment to reproductive stage(Nemoto et al. 1992).

We have classified GFT of plant into three types. The first type is the position fortifying tactics (PFT), the second type is position extending tactics (PET) and the third is unconstrained type which can use properly the above mentioned two tactics. We have defined "position" as the space for biomass production occupied by leaves and stems or culms of particular individual plants. PF is a tactic for the plant to hold the area around its germination point. This type of plant elongates its stem in the vertical direction and develops its leaves three dimensionally and is competitive against surrounding plants (Yamagata & Nemoto 1992). *Rumex obtusifolius* and *Echinochloa crus-galli* belong to this type. On the other hand, PE plants are weak in competition with others, but quickly elongate their stems horizontally to search for the unused space nearby. *Duchesnea chrysantha, Trifolium repens, Zoysia japonica* and *Mazus miquelii* are examples of this type.

PF type plants elongate stems vertically from the germination point and develop leaves. In competition with neighboring plants, the taller leaves give these plants a competitive advantage. PF type plants invest their resources tactically to hold their present position. This is why we have termed this tactics as "position fortifying". On the otherhand, PE type plants elongate stems horizontally, and new roots emerge from the stem when it locates open space around it. PE type are weak in competition because they are easily shaded by neighbouring plants. PE type plants have the growth tactics to invest their growth resources toward extending their positions rather than holding the old positions. This is why we have used the term of "position extend" tactic.

Plant species of unconstrained type such as *Digitaria ciliaris, Commelina communis* and *Paspalum conjugatum* are likely to occupy the living space in response to the circumstances around it. When this type of weed invades in open space, the growth form becomes like PE type. By contrast, in grassland gaps, it becomes like PF type.

Potential plant size

Potential plant size (PPS) is expressed by the three-dimensional space based upon the combination of plant height and growth form. As shown in Fig. 1, PPS of weed species can be divided into three types, small, intermediate and large. Large type weed belongs to tall-growing and can horizontally expands the space occupied. While small type weed possesses the opposite properties.

Table 2. The matrix of the magnitude of effects of a weed plant in grassland on neighbouring plants, target crop or other weeds

PPS of a weed plant	PPS of neighboring plants (target crop or other weeds): S	I	L
S	−∼0	0∼+	0∼++
I	−−	−∼0	0∼+
L	−−−	−−	−∼0

note: PPS: potential plant size, S:small, I: intermediate L:large, -competitive effect. +cooperative effect.

The matrix of the magnitude of effects of a weed plant in grassland on neighbouring plants, target crop or other weeds is shown in Table 2. This matrix is made up of the factor of PPS of the weed species. In cases where the large type plant is the target species, the sustainability of communities which are mainly composed of this species may increase in proportion to the richness of small type weeds. The number of small type weeds coexisting in this community, however, may be determined by the growth form property of the target plant (Nemoto, Ohkuro & Mitchley 1993). While in cases where the small type plant as the target species, the sustainability of the community may be determined by the frequency and intensity of mowing or grazing and by the reduction of fertilizer application because such management treatments are appropriate for the suppression of the vigor of neighbouring plants.

Weed species richness and conservation value

The conservation of ecosystem is the concept of realizing the sustainable use of system and is the most basic viewpoint of agro-ecosystem management (Nemoto 1994). For this purpose we should clarify the objectives for utilization and manage to accomplish these objectives. The continuous invasion of harmful weeds reduces the conservation value of agro-ecosystem. In this section the role of weed species richness as an uninvited guest existing in agro-ecosystem will be discussed from the viewpoint of biodiversity and conservation value.

Weed species richness is maintained in *Imperata cylindrica* dominated grassland on embankment slopes by cutting twice, June and October, in a year. However, in a no-cutting condition the species richness decreases and *Miscanthus sinensis* becomes dominant (Asami et al. 1994). This fact indicates that traditional management of the rural landscape provides an agro-ecosystem of high conservation and amenity value with enhanced weed species richness compared with both the intensively managed and the unmanaged situations(Green 1985).

However, weed species richness is not always positive towards the conservation value of grassland. For example, the weed species in well managed sown meadow where *Dactylis glomerata* is dominated is richer in the early stage of establishment and in the mature stage compared with the intermediate stage (Nemoto unpublished). Weed species like *Erigeron* spp., *Commelina communis* and *Digitaria ciliaris* of tall-growing type often emerge and develop in the early stage of establishment and are competitive against *D. glomerata.* Therefore the conservation value of this type of species richness is low. However, weed species like *Mazus miquelii* and *Sagina japonica* of short-growing type increase in the mature stage. These species are cooperative with *D. glomerata* and some of these species can suppress the emergence of the seedlings of tall-growing weeds. Therefore this type of species-richness enhances biobiversity and contributes to agro-ecosystem conservation value. Thus it is the nature of the interrelation between weed plants and target plants in the managed grassland agro-ecosystems that determines whether the weed species richness enhances or reduces biodiversity and consequently provides positive or negative conservation value.

References

Asami, K., Akamatsu, H., Hattori, T. & Tsuji, H. 1994 Ecological studies on management of grassland vegetation on the embankment slope 3. *Humans and Nature,* 4, 81-97.

Green, B. 1985 *Countryside conservation, the protection and management of amenity ecosystems.* pp.253, London: George Allen & Unwin.

Gimingham, C. H. 1951 The use of life form and growth form in the analysis of community structure, as illustrated by a comparison of two dune communities. *Journal of Ecology*, 39, 396-406.

Grubb, P. J. 1977 The maintenance of species richness in plant communities: The importance of the regeneration niche. *Biological Reviews*, 52, 107-145.

Grubb, P. J., Kelly, D. & Mitchley, J. 1982 The control of relative abundance in communities of herbaceous plants. In: Newman,E.I.(ed.). *The Plant Community as a Working Mechanism.* pp.79-97. Oxford:Blackwell.

Mitchley, J. 1994 Sward structure with regard to conservation. In:Haggar, R. J. & Peel, S. (ed.). *Grassland management and nature conservation*. pp.43-53. Aberystwyth:British Grassland Society.

Nemoto, M. & Kanda, M. 1976 A study on the grassland weed community under different cutting conditions (1). *Bulletin of the Institute for Agricultural Research, Tohoku University*, 27, 69-88.

Nemoto, M. & Numata, M. 1979 Ecological characteristics of short-growing weeds in sown meadows. *Proceedings 7th Asian-Pacific Weed Science Society*. 367-370.

Nemoto, M., Yamagata, Y., Ohkuro, T. & Mitchley, J. 1992 Growth form tactics of plants with special reference to annual grass weeds. *Weed Research, Japan,* 37, Supplement 1. 20-21.

Nemoto, M., Ohkuro, T. & Mitchley, J. 1993 Gap characteristics and growth form tactics of colonizing weeds in sown meadows. *XV International Botanical Congress*. Abstracts, 45.

Nemoto, M. 1994 Use of weeds for agro-ecosystem conservation. *Farming Japan,* 28, 17-23.

Niiyama, T. & Numata, M. 1969 Interspecific density effect of upland rice on the allowable limit of weeds-competition between a crop and weeds, 3. *Japanese Journal of Ecology*, 19,147-15 4.

Oki, Y., Ishiyama, C. & Ohmine, T. 1995 Maintenance of vegetation composed of available weedy plants as a cover plant and their competition with other invading weeds. *Weed Research, Japan,* 40, Supplement 1. 120-121.

Yamagata, Y. & Nemoto, M. 1992 Spatial competition model of plant growth form strategy. In: Shiyomi,M., Yano,E., Koizumi,H., Andow,D.A. & Hokyo,N.(ed.) *Ecological processes in agro-ecosystems*. pp.47-54. Tokyo:Yokendo Publishers.

Weed Communities on Set-Aside Land in Great Britain:
Balancing the Desirable and the Undesirable.

F M Burch, J Mitchley & B H Green

Environment Section, Wye College, University of London, Kent TN25 5AH, UK.

Abstract. The set-aside scheme was introduced in Britain in 1988 as a method of reducing surplus production in the arable sector. Land is withdrawn from production and a green cover established by sowing or natural regeneration. Although introduced as a supply control, the scheme offers potential environmental benefits, such as biodiversity enhancement, since given appropriate conditions a wide range of "desirable" species will colonise set-aside and species-rich grassland may develop. However, the control of "undesirable" species (e.g. problem weeds) is important. Balancing weed control with suitable establishment conditions for desirable species is necessary to achieve the potential for biodiversity enhancement of set-aside land. A large-scale field experiment was set-up at Wye College to investigate this balance. Five establishment methods were compared, including natural regeneration and sown grass covers, and seeds of problem weed and stress-tolerant grassland species sown to study the effect of the establishment methods on control of undesirable species and establishment of desirable species. Results after one year suggest two approaches for achieving a balance between weed control and colonisation by desirable species. Where weed control is the primary concern, a "temporal balance" may be appropriate where a vigorous grass cover is sown, providing weed control in the first year followed by the potential spread of desirable species as the sown sward senesces. Alternatively, a "spatial balance", with a less vigorous establishment treatment, creates a more open matrix in the first year offering partial weed control as well as more favourable establishment conditions for desirable species.

Key words. biodiversity enhancement, competitive exclusion, grass cover, natural regeneration, stress-tolerant species, weed control.

Introduction

The set-aside scheme was introduced into Great Britain in July 1988 as part of a European Community initiative to reduce surplus production in the arable sector. The scheme operates by paying farmers to remove areas of land from production on a rotational (1 year) or semi-permanent basis (5 or 20 years duration). Although originally a voluntary scheme, set-aside (at a rate of 15 - 18% of arable area) is now mandatory for all farmers wishing to receive subsidies for arable production. Farmers are required to establish a green cover on set-aside land either by allowing natural regeneration or by sowing a cover crop, usually of grass and maintaining the sward by cutting at least once a year to control problem weeds. Set-aside has received opposition from many environmentalists who favour more targeted schemes, however, set-aside now represents a major new land use in much of Europe and the opportunity exists to maximise the environmental benefits of the scheme.

A number of botanical surveys have illustrated the potential of set-aside to enhance biodiversity in the agricultural landscape (Wilson 1992; F M Burch unpublished). Set-aside land is usually dominated by annuals in the first year, e.g. *Anisantha sterilis* (L.) Nevski, *Alopecurus myosuroides* Hudson and *Papaver rhoeas* L. (Nomenclature follows Stace 1991). These are soon replaced by perennials, including problem weeds, e.g. *Elytrigia repens* (L.) Desv. ex Nevski, *Cirsium* spp Miller and *Rumex* spp. L., which are undesirable species from the farmer's viewpoint. However, not all so-called "weeds" are undesirable from a nature conservation perspective, and in first year set-aside some uncommon arable weeds may be found e.g. *Euphorbia exigua* L., *Kickxia* spp Dumort. and *Legousia hybrida* Durande. More surprising is the range of other species that have been recorded in recent set-aside, e.g. stress-tolerant species typical of species-rich limestone grassland habitats, such as *Pimpinella saxifraga* L., *Polygala vulgaris* L., *Sanguisorba minor* Scop. and *Scabiosa columbaria* L. Many of these species are uncommon in the wider countryside due to loss of their natural habitats as a result of agricultural intensification in recent decades. The reappearance of these desirable species on set-aside land represents a potential major environmental benefit of the set-aside scheme.

Three factors affect the potential of set-aside to enhance biodiversity in the wider countryside. Firstly, the location of set-aside land in relation to existing wildlife habitat is important both as a means of extending and buffering existing habitats and as a potential source of propagules colonising set-aside. Secondly, the method used to establish a green cover influences both the colonisation of desirable species and the control of undesirable species. Thirdly, the subsequent management of set-aside will favour different desirable and undesirable species depending on the frequency and timing of cutting regimes and whether the cuttings are left on the ground or removed. This paper reports an experiment designed to investigate the balance between weed control and establishment of desirable species on set-aside.

Materials and Methods

An experiment was set up at Wye College in autumn 1993 to study the effects of a range of establishment methods on the control of problem weeds and the establishment of sown permanent grassland species. The experimental field is on the west-facing, gently sloping, chalk escarpment. The soil is a shallow calcareous grey rendzina (mean pH 8.4), of low fertility and mean soil depth above the chalk of less than 30cm. The field was selected to represent marginal arable land of low productivity which might be targeted by farmers for set-aside, and which could be expected to develop into a species rich vegetation community of conservation value. The experimental site is bounded by an arable field to the west, permanent pasture to the north, woodland to the east and an existing long-term set-aside experiment to the south.

The experimental design was a 5 x 5 latin square to take account of the horizontal and vertical gradients of slope and neighbouring vegetation across the site. There were 5 establishment treatments, 2 problem weed treatments (undesirable species) and 6 sown permanent grassland species treatments (desirable species) all replicated five times giving 5 x 2 x 6 x 5 = 300 treatment sub-plots each measuring 2 x 2 m (Table 1; Figure 1). The site was ploughed and sown in September - October 1993 and management is by an annual cut in August with the cuttings left on. The development of vegetation was recorded in spring and again in autumn 1994 in permanent 1 m x 1 m quadrats positioned in the centre of each of the sub-plots. Each quadrat was gridded in twenty-five, 20 cm x 20 cm cells and a full species list was recorded for the whole 1 m quadrat together with cover estimates of all species recorded. In eight of the sub-cells, seedlings of the sown grassland species were counted and their percentage ground cover estimated by eye. To study the establishment environment in which the seedlings were developing the percentage cover of the sown grass matrix, other grasses, forbs, bare ground and litter were recorded.

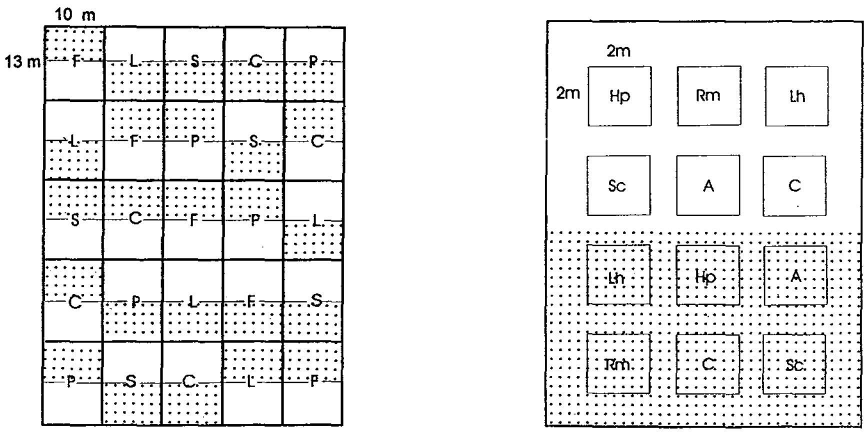


Figure 1 The experimental design showing (left) the whole experiment and (right) detail of one establishment plot showing treatment sub-plots. Shaded areas are the weed treatment. S = natural regeneration after stubble; P = natural regeneration after ploughing; L = *Lolium*; F = *Festuca*; C = *Cynosurus*. Other symbols refer to the sown desirable species treatments and are indicated in Table 1.

Analysis of the establishment treatments was carried out using ANOVA (GENSTAT) with data transformation as required to achieve homogeneity of variance. Orthogonal contrasts identified significant differences between treatments and Pearson correlation coefficients and linear regression tested relationships between variables. Only data for treatments involving one of the sown desirable species, *Leontodon hispidus* L., are discussed in this paper except where otherwise stated.

Table 1 Treatments used in the Wye College establishment field experiment

Five establishment treatments (10 x 13 m)	Two weed treatments (undesirable species) (10 x 6.5 m)	Six permanent grassland species treatments (desirable species) (2 x 2 m)
• Natural regeneration from stubble of previous barley crop	• *Anisantha sterilis* (50 seed m^{-2}) *Rumex obtusifolius* (200 seed m^{-2})	• *Leontodon hispidus* (3.4 gm^{-2}, 500 seed m^{-2})
• Natural regeneration after ploughing	• None sown	• *Helictotrichon pubescens* (Hudson) Pilger (4.4 gm^{-2}, 500 seed m^{-2})
• *Lolium perenne* L. (2 gm^{-2}, 1250 seed m^{-2})		• *Scabiosa columbaria* (3.9 gm^{-2}, 500 seed m^{-2})
• *Festuca rubra* ssp *commutata* Gaudin (1.2 gm^{-2}, 1250 seed m^{-2})		• *Rhinanthus minor* L. (5.6 gm^{-2}, 500 seed m^{-2})
• *Cynosurus cristatus* L.(0.9gm^{-2}, 1250 seed m^{-2})		• All the above (125 seed m^{-2} each)
		• None sown

Results and Discussion

Establishment environments and control of weeds

By the first monitoring period the stubble treatment provided a very different environment from the other four establishment methods (Figure 2a,b). The lack of cultivation led to early domination by grasses such as *Elytrigia repens* and *Poa trivialis* L. and a significant cover of barley straw remained from the previous crop. In the four cultivated treatments, bare ground was much greater as was the cover of unsown forbs; dominated in the first monitoring by *Papaver rhoeas*. The sown grass matrix was only a significant component in the *Lolium* treatment, where sown grass cover averaged 32%. In the *Festuca* and *Cynosurus* treatments, sown grass cover averaged only 5%

a) Spring, no weed treatment b) Spring, weed treatment

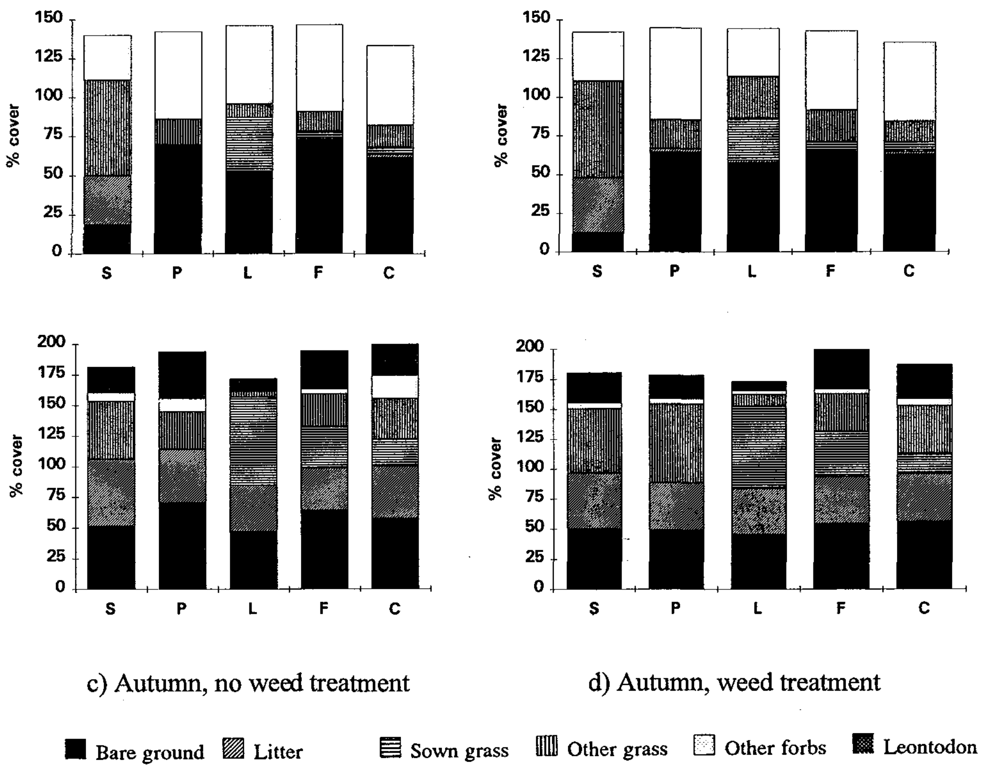


Figure 2 Establishment environments in the *Leontodon* treatment plots in spring and autumn 1994. Bars show mean percentage cover of five replicates, for key to establishment treatments see Figure 1.

By the second monitoring (Figure 2c,d) the differences between establishment methods and between weed treatments had become much more pronounced. The most marked difference was the development of the sown grass matrix. The *Lolium* treatment averaged a sown grass cover of 70% which dominated the vegetation competitively excluding most other species. In comparison, the *Festuca* treatment averaged 38% cover, while *Cynosurus* averaged only 20%, reflecting clear differences in germination, early establishment and growth rate of the sown grasses. The effect of these sown covers on weed control is illustrated by comparing the cover of other grasses (dominated at this stage by *Anisantha sterilis, Elytrigia repens, Poa trivialis*) both between establishment treatments and between the weed and non-weed treated plots. In the *Lolium* treatment, percentage cover of other grasses was minimal (5% in non weed plots, 10% in weed treated plots, while in the weed treated ploughed plots, other grasses averaged 66% cover, there being no sown grass matrix to compete with the additional weeds. Analysis of selected problem weed species (*Anisantha sterilis, Elytrigia repens* and *Rumex obtusifolius*) reinforced this result, with the *Lolium* treatment providing the best control ($P < 0.001$) and the ploughed treatment the least ($P = 0.009$) when contrasted with all other treatments.

Establishment of Leontodon hispidus (Compositae)

Leontodon is a polycarpic perennial, stress tolerant rosette hemicryptophyte, typical of dry limestone grasslands in Europe (Grime, Hodgson and Hunt 1988). Regeneration is by clonal spread and by wind dispersed seeds which germinate in vegetation gaps. At the first monitoring there was already a clear trend towards greater establishment success in the sown grass treatments (Figure 3a), with the greatest number of seedlings occurring in the *Festuca* and *Cynosurus* treatments and the least in the stubble plots. Orthogonal contrasts indicate a significant difference in seedling numbers between the stubble treatment and all other treatments ($P = 0.022$) , and between the stubble treatment and the three sown cover treatments ($P = 0.015$). The stubble treatment creates an establishment environment which is less favourable to *Leontodon* due to the dominance of weed grasses, such as *Elytrigia repens* and *Poa trivialis* and the higher cover of litter and reduced bare ground. There was a significant negative correlation between numbers of *Leontodon* seedlings and percentage cover of litter in the non weed treated plots ($P < 0.05$) and a significant positive association with bare ground cover ($P < 0.05$) in the weed treated plots. It may be concluded that the availability of bare ground for seedling establishment in spring is an important factor influencing the establishment of *Leontodon*.

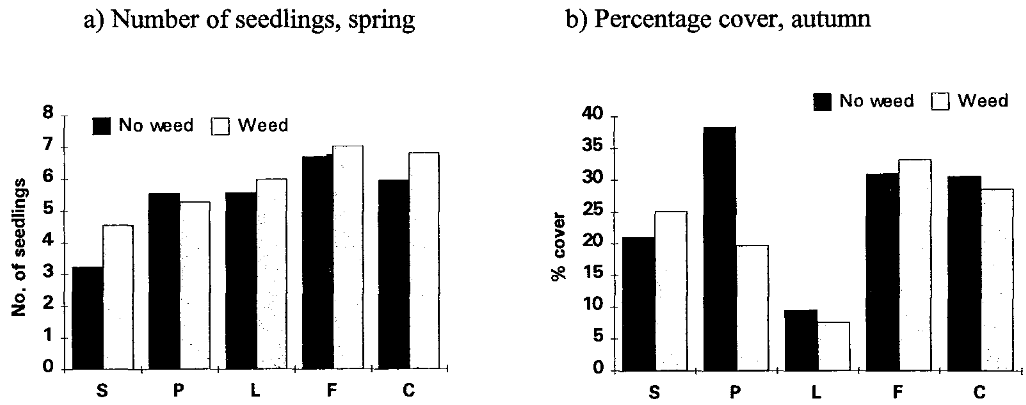


Figure 3 Establishment of *Leontodon hispidus* in 1994 (key to establishment treatments see Figure 1).

At the second monitoring there was a significant effect of establishment treatment on the cover of *Leontodon* ($P = 0.011$; Figure 3b). Orthogonal contrasts revealed a very highly significant difference between the *Lolium* treatment and the other two sown swards ($P < 0.001$) and between the *Lolium* treatment and all other establishment treatments ($P = 0.001$). High cover of *Leontodon* was recorded in the *Festuca* and *Cynosurus* treatments (mean of 32% and 30% respectively). However, a high cover of *Leontodon* (38%) was also found in the non-weed treated ploughed plots and the more open conditions of this treatment provided a more favourable environment for the spread of *Leontodon* individuals. In contrast, cover of *Leontodon* was significantly reduced in the *Lolium* plots (9% in weed treated, 7% in non-weed treated). The establishment environment in the *Lolium* treatments in autumn was dominated by a high percentage cover of sown grass which provided the least favourable conditions for vegetative spread by *Leontodon* plants (Figure 2c,d). The influence of grass cover on *Leontodon* had long-lasting effects as evidenced by the significant negative relationship between cover of *Leontodon* in autumn and the total grass cover (sown grasses plus other grasses) in the previous spring (P = 0.001, Figure 4). It is important to note that the low cover of *Leontodon* in the *Lolium* treatment in autumn did not reflect a reduction in the number of *Leontodon* plants. In fact, in terms of numbers of individuals, the *Lolium* treatment provided an establishment environment at least as favourable to *Leontodon* as the two natural regeneration treatments and the two other sown grass treatments. Thus in the *Lolium* treatment, *Leontodon* plants were surviving but were unable to expand their cover. As a stress tolerant species, however, it may be that these plants, although small, may persist in the longer term.

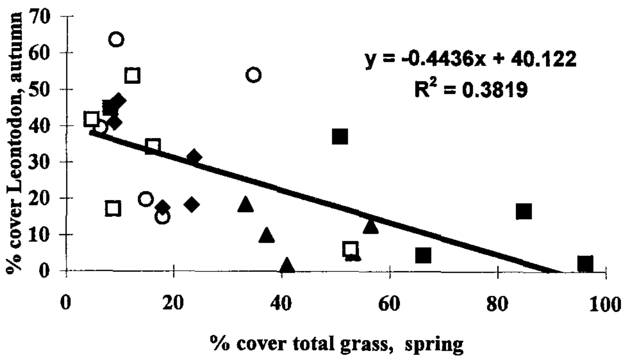


Figure 4 The relationship between grass cover in spring 1994 and the cover of *Leontodon* in autumn. ■ = S, O = P, ▲ = L, ◆ = F, □ = C. For key to establishment treatments see Figure 1.

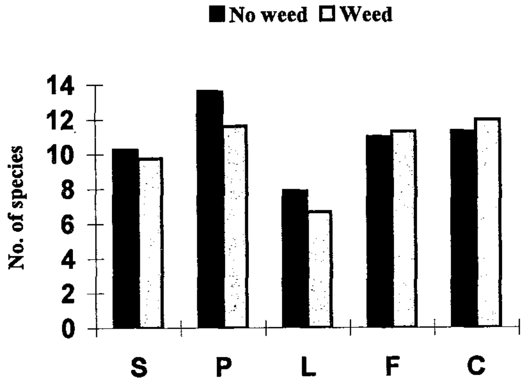


Figure 5 The effect of establishment treatment on species richness (mean number of species per 1m x 1m quadrat) in autumn 1994.

Species richness

In the first year of the experiment the vegetation was dominated by ruderal species characteristic of disturbed arable land, e.g. annuals such as *Anisantha sterilis, Lamium purpureum* L. *Papaver rhoeas, Veronica persica* Poiret) and biennials and competitive perennials such as *Cirsium vulgare* (Savi) Ten. and *Elytrigia repens*. Even at this early stage in the experiment grassland species had started to colonise from the adjacent set aside experiment (e.g. *Daucus carota* L., *Leucanthemum vulgare* Lam.) as well as species from the woodland above (*Geum urbanum* L., *Fraxinus excelsior* L.). Figure 5 shows the mean species richness for all establishment treatments using data for the complete experiment at the autumn monitoring. The general trends discussed for *Leontodon* above are also reflected in these results, with, the *Lolium* treatment reducing species richness and the ploughed treatment enhancing species richness when contrasted with all other treatments (P <0.001). The more open establishment environment of the ploughed treatment clearly offered greater opportunity for colonisation by a variety of species, while the dense *Lolium* sward offered much reduced colonisation opportunities. However in all treatments most of the species are ruderals some of which are problem weeds. The annual species such as *Papaver rhoeas*, are unlikely to persist in the longer-term since they are reliant on disturbance and creation of new bare ground to establish from a persistent seed bank. However, the perennial species (problem weeds as well as the permanent grassland and woodland species) may persist in the longer term depending on the subsequent management of the set-aside land.

Conclusions

The results of this experiment illustrate the importance of establishment treatments in determining the species composition of first year vegetation developing on set-aside land. Natural regeneration after ploughing results in a species-rich vegetation composed of ruderal species (including problem weeds), while sowing a *Lolium perenne* cover results in a dense sward of *Lolium* with few associated species.

In situations where weed control is the overriding objective, especially in locations where problem weeds are likely to be abundant in the seed bank or seed rain, the best treatment is to sow a cover of *Lolium* *perenne* whose early and rapid growth competitively excludes most weed species. This must be balanced against the reduced opportunities for colonisation, and particularly for vegetative expansion of desirable species and the associated reduction in overall species richness. However, the results show that individuals of desirable species are able to survive in the *Lolium* sward albeit at reduced growth rates. There is evidence that without careful sward management *Lolium* declines in vigour in the longer-term (Charles & Haggar 1978). Species of limestone grasslands are characteristically stress tolerant, tolerating levels of nutrient stress and defoliation and coexisting in diverse communities (Grime *et al* 1988). Such species are likely to be adapted to survive the initial period of *Lolium* domination and may be able to spread in the longer term as the *Lolium* matrix declines.

In terms of achieving a balance between weed control and establishment of desirable species, *Lolium* and natural regeneration after ploughing represent the two extremes in the early stages of vegetation establishment. However, it may be that *Lolium* provides a "temporal balance" in the sense that early weed control in the first year is followed by the potential for spread of desirable species as the *Lolium* declines. Alternatively, a balance between weed control and establishment of desirable species may be achieved through a "spatial balance" in which an establishment treatment is used which, in the first year, creates a more open matrix providing partial weed control as well as favourable conditions for establishment of desirable species.

From the first year results *Festuca rubra* ssp. *commutata* appears to provide just such a spatial balance, with moderate weed control and good establishment opportunities for desirable species. However, while *Festuca rubra* is relatively slow to establish, in the second year it forms a dense thatch with persistent litter and competitively excludes most other species (Smith *et al* 1971). It therefore appears to be a poor option for biodiversity enhancement. The two other establishment treatments discussed here, natural regeneration from stubble and sown cover of *Cynosurus cristatus*, may be better options for providing spatial balance. Of the two, *Cynosurus* appears to provide intermediate control of weeds as well as favourable opportunities for both establishment and spread of desirable species.

For the creation of species-rich grassland communities on set-aside land, we propose two contrasting approaches to achieving the balance between desirable and undesirable species. Where weed control is the principle concern, a temporal balance is most appropriate in which weed control precedes biodiversity enhancement. In situations of reduced weed infestation, a spatial balance is a better option since weed control and biodiversity enhancement are synchronised, providing the most favourable environment for the early establishment and spread of desirable species on set-aside land.

Acknowledgement

FMB was supported by a research studentship from the Ministry of Agriculture, Fisheries and Food.

References

Charles A H & R J Haggar 1978. *Changes in Sward Composition and Productivity.* British Grassland Society Occasional Symposium No 10. Berkshire: British Grassland Society.

Grime J P, J Hodgson and R Hunt. 1988. *Comparative Plant Ecology.* London: Unwin Hyman.

Smith C J, J Elston & A H Bunting. 1971. The effects of cutting and fertiliser treatments on the yield and botanical composition of chalk turf. *Journal of the British Grassland Society*, **26,** 213-219.

Stace C. 1991. *New Flora of the British Isles.* Cambridge: Cambridge University Press.

Wilson P J. 1992. The natural regeneration of vegetation under set-aside in Southern England. In: *Set-aside.* J.Clarke (ed.). pp. 73-78. British Crop Protection Council Monograph No 50. Farnham: BCPC Publications.

Revegetation of Embankment Slopes with Cogongrass (Imperata cylindrica var. koenigii)*

Kayo ASAMI ** ·Hiroji AKAMATSU ** ·Tamotsu HATTORI ***

** Institute of Rural & Urban Ecology, Higashinakajima 4-11-32-602, Higashiyodogawa-ku, Osaka, 533 Japan

*** Himeji Institute of Technology Institute of Natural and Environmental Science, Hyogo, Yayoigaoka 6, Sanda, 669-13 Japan

Abstract. This report clarifies the relationship between grassland management and vegetation on embankment slopes and suggests cogongrass as a material for slope planting and landscaping. For several years we investigated the effects of different frequency of cutting on growth and species composition of the vegetation on the embankments of three rivers. We found that eulaliagrass (Miscanthus sinensis) and cogongrass dominated under the management of one cutting per year, cogongrass dominated with two cuttings per year and Japanese lawn grass (Zoysia japonica) dominated with three cuttings per year. We also determined that the species diversity of cogongrass grassland cut twice a year was high and there was a clear seasonal change in terms of ratio of therophytes, found in spring and autumn. This indicates cogongrass grassland is appropriate for open space and grassland biotope. The rhizomes appropriately protect the embankments from soil erosion and this grassland is one of the traditional parts of the Japanese rural landscape. Thus we propose that cogongrass is appropriate for grassland on embankment slopes, and, we are now test planting on the embankments of some rivers.

Key words revegetation, embankment slope, Imperata cylindrica var. koenigii

*This paper is a conflation, revision, and expansion of two earlier studies, the Journal of the Japanese Institute of Landscape Architecture Vol. 58 March 1995 and the Humans and Nature No. 4 December 1994.

Introduction

Cogongrass is one of the aggressive weeds in crop fields, orchards, as well as lawns in Japan and some other countries throughout the temperate and tropical regions. We will mainly discuss the usefulness of cogongrass on embankment slopes from the points of view of soil erosion prevention, sustainability and the environment, and mention will be made of some actual cases of utilization.

Generally, when embankments are built, the surfaces of the slopes are sodded with Japanese lawn grass. The reason for this is its superior ability to prevent soil erosion. Afterward, the Japanese lawn grass grassland is maintained the standard way, that is, hand-weeding for three years and after that cutting twice a year. During the first three years of hand-weeding, the Japanese lawn grass grassland is kept in good condition, but then after several years the grassland changes to that dominated by other grasses such as cogongrass, eulaliagrass, tall goldenrod (Solidago altissima), Japanese mugwort (Artemisia princeps), Japanese knotweed (Polygonum cuspidatum), broomsedge (Andropogon virginicus) etc. This suggests the necessity of another plant of superior sustainability to replace Japanese lawn grass and of a way of properly maintaining the vegetation of embankment slopes.

Ezaki [3] has studied the usefulness of cogongrass and eulaliagrass, which are common weeds on the slopes of embankments, as well as several other species which had been planted there, from the viewpoint of disaster prevention. From the esthetic point of view, there have been attempts to establish amenity grassland in horticultural cultivars for the vegetation of embankment slopes [6]. But there have been no studies on the present condition of embankment slopes.

We investigated the relationship between cutting frequency and vegetation. Based on the results of this investigation, this study also intends to discuss the desired vegetation, selected from the wild flower community. Furthermore, the authors will review the revegetation tests that have been conducted to actually establish this vegetation.

Method

Cutting test

The cutting tests were conducted with grassland on the embankment of the Ina river in Hyogo Pref. (A) [5], the Niyodo river in Kochi Pref. (B) [2] and the Naka river in Tokushima Pref. (C) [1]. These locations are shown in Fig. 1.

The dominant species in the test sites were cogongrass, eulaliagrass, tall goldenrod and Japanese lawn grass etc. In each study site which had originally been cut twice a year we established four plots of different cutting frequencies. The cutting frequencies are as follows; "no cutting", the condition where no cutting is done; "one cutting every two years", where one cutting is done every two years; "one cutting per year", where one cutting is done per year; "two cuttings per year", where two cuttings are done per year; and "three cuttings per year", where three cuttings are done per year (Table 1). Each plot contained five quadrats of one square meter.

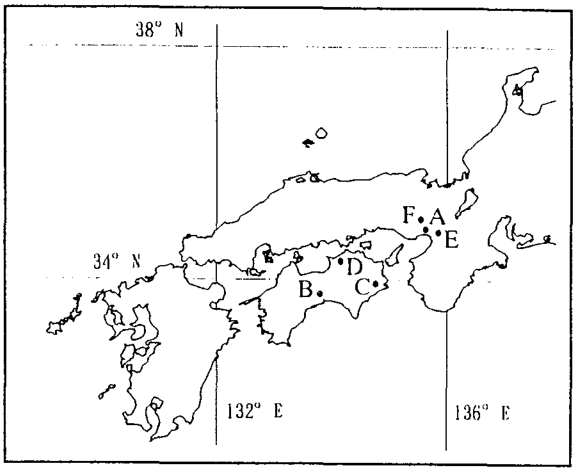


Fig. 1 The locations of the study sites. A : The Ina River in Hyogo Pref., B : The Niyodo River in Kochi Pref., C : The Naka River in Tokushima Pref., D : The Doki River in Kagawa Pref., E : The Yodo River in Osaka Pref., F : Sanda City in Hyogo Pref.

Table 1. Cutting frequency and cutting month

cutting frequency	cutting month		
(study site)	(A)	(B)	(C)
No cutting	–	–	–
1 cutting per every two years	Aug.	*	Jun.
1 cutting per year	Jun. ~ Jul.	Aug.	Jun.
2 cuttings per year	Jun. ~ Jul.and Oct. ~ Dec.	Aug. and Sept. ~ Oct.	Jun. and Oct.
3 cuttings per year	*	Jun. and Aug. and Sept. ~ Oct.	*

Study sites (A – C) correspond to those in Fig.1. Asterisk means no plot in the study site.

We listed all species and measured the average height and coverage of each plant in each quadrat. We documented their progress every spring, summer and autumn for four years. The cutting treatment consisted of all the aboveground parts being cut at ground level in each quadrat and removed.

For the purposes of analysis, the weighted mean of height of each species, the arithmetic mean of coverage of each species and the number of species in the five quadrats provided the results of each plot. Diversity indices, Simpson's 1/d ($=1/(1-\Sigma P_i^2)$, $P_i = (H'+C')/2$) were calculated for each plot, where P_i indicated the product of cover ratio and height ratio of the ith species. The number of species was that found in the plot.

The "height of a community" is the average, for each cutting frequency, of the individual weighted means calculated separately for each plot, the mean of each plot being that of the taller grasses in the plot. These taller grasses include those such as eulaliagrass, tall goldenrod, etc., which themselves determined the aspect of the community of each plot.

Revegetation test

The two methods of revegetation using cogongrass are planting and seeding. The tests were conducted with grassland on the embankments or the flood plains of the Ina river in Hyogo Pref. (A), the Doki river in Kagawa Pref.(D), the Yodo river in Osaka Pref. (E) and the Sanda city in Hyogo Pref. (F). These locations are shown in Fig. 1.

Planting of cogongrass was done with rhizomes collected in their native habitat and planted by linear revegetation the next day. But, now cogongrass (and its rhizomes) can be purchased at 40 yen each.

Seeding was executed as follows: We collected this year's new seeds from their native habitat, examined the seed fertility and germination, and sowed the quantity of seeds necessary for the amount of germination desired. There were three methods of sowing; one was the painting of seeds mixed with sand and water, the second was the spraying of seeds with water and a water holding substance, and the third method was sowing directly.

Results

1.Cutting test

Table 2 summarizes the relationship between frequency of cutting and the vegetational characteristics (height, cover, number of species, species diversity) as determined from these tests. The grassland type established by each cutting treatment was named according to the dominant species in the plot. The dominant species name was used where coverage exceeded 25%. In cases of less than 25% coverage, the species name was bracketed.

Table 2. The relationships between cutting frequency and ecological characteristics four years after starting the cutting test.

cutting frequency	type of community	Number of study sites	Height in Aug.	Variety of species	Diversity of species (1/d)	Seasonal aspect by appearance of therophytes
No cutting	eulaliagrass type	3	1.50m	poor	low	obscure
1 cutting every two years	eulaliagrass type or [cogongrass] type	2	1.30m	poor	low	obscure
1 cutting per year	eulaliagrass type or cogongrass type	3	0.75m	medium	medium	obvious
2 cuttings per year	cogongrass type or [eulaliagrass] - [cogongrass] type	3	0.50m	abundance	high	obvious
3 cuttings per year	Japanese lawn grass - cogongrass type	1	0.35m	poor	low	obvious

It is clear that grassland types are related cutting frequency, as described below.

In the "no cutting" plots and the "one cutting every two years" plots, the grasslands were dominated by eulaliagrass which was over 1.2m in height. These grasslands were named eulaliagrass type. In the "one cutting every two years" plots in study site C, cogongrass was extremely dominant and eulaliagrass didn't grow at the start of this test. As the coverage of cogongrass in this plot was 20% four years after the start of the test, this grassland type was named [cogongrass] type. It is expected that this will change to eulaliagrass type in the near future, since eulaliagrass seedlings were found outside of the quadrats in the plot at the end of this test. Due to the relative scarcity of therophytes in these grassland types, no conclusions could be drawn about seasonal aspects. Of special note, the number of species and species diversity were extremely reduced in the "no cutting" plots.

In the "one cutting per year" plots, the grasslands were dominated by cogongrass (cogongrass type) where cogongrass was the dominant species at the beginning of the study. But in the case of eulaliagrass being the initial dominant species, the grasslands were still dominated by eulaliagrass (eulaliagrass type).

In the "two cuttings per year" plots, the grasslands were mostly dominated by cogongrass at the end of this test. The grassland types were cogongrass type and [eulaliagrass] – [cogongrass] type. In all of these plots, the number of species and species diversity were very abundant, and the seasonal aspects were clear by the appearance of many therophytes.

In the "three cuttings per year" plot, the grassland was dominated by Japanese lawn grass ([Japanese lawn grass] type). This type had the lowest height, and displayed seasonal aspects with the appearance of therophytes. The number of species and species diversity in this type were abundant, but not as abundant as those in the cogongrass type or the eulaliagrass type in the "two cuttings per year" plots.

2.Revegetation test

Table 3 summarizes the details of methods and the existing state of the planting test. The best planting season is from February to July. During early maintenance, it is important for survival of cogongrass to water the planted area. If plant density is from fifty to sixty per square meter, and roots take well, the aspects of the grassland will look relatively like that of the native cogongrass grassland. The weeds, which include many therophytes, invade the grassland, but the cover of them is low.

Table 3. Summary of seven experimental fields planted with Cogongrass

Study site	A	A	E	E	D	D	F
Date of planting	Jun.1988	Jul.1989	Sep.1989	Jul.1991	Jun.1989	Jun.1991	Jun.1993
Field size (m²)	10	10	3	1	3	6	30
Planting density (/ m²)	60 ~ 100	60	60	60	60	60	50
Initial maintenance	Cutting	Watering, Cutting	Watering	Watering	Watering	Watering	Watering
Initial phase (grassland type)	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass
Present phase (grassland type)	Weed	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass

Study sites (A –C) correspond tu those in Fig.1.

Table 4 summarizes the details of methods and the existing state of the seeding test. Generally, the germination ratios were high in each location, but fertility ratios were extremely irregular. The seeding season is restricted to that ranging from the spring to the rainy season. It is also important for germination and survival to water the seeding area. The early growth is very slow. Even in the site where the best growth was observed, the height of cogongrass was only about 20cm one year later. In many cases cogongrass was covered with weeds which interfered with its growth. Thus it is necessary to either remove the weeds or to otherwise prevent their invasion. But even in where germination and early growth conditions were bad, cogongrass dominated three years later in most sites.

Table 4. Summary of seven experimental fields seeded with Cogongrass

Study site	A	A	E	E	D	D	F
Date of seeding	Jun. 1988	Jul. 1989	Sep. 1989	Jul. 1990	Aug. 1989	Jun. 1991	Jun. 1993
Field size (m²)	300	500	100	125	24	24	200
Seeding density (/ m²)	10000	10000	7500	12000	10000	10000	5900
Initial maintenance	Cutting	Watering, Cutting		Watering	Watering		Watering, Cutting
Number of species in mixed seeds	6 ~ 33	5	1	1	1	1	11
Initial phase (grassland type)	Weed	Weed	Weed	Weed	Weed	Cogongrass	Cogongrass
Present phase (grassland type)	Weed	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass

Study sites (A –C) correspond tu those in Fig.1.

Both planting and seeding require no fertilizers, as they encourage the luxuriant growth of the weeds, which are It follows from what has been said that planting had advantages over seeding in that the planting season was long, it was easy to maintain in the early stages and cogongrass was endowed with marketability. On the other hand, over a large area seeding cogongrass was easier than planting.

Discussion

1.Prevention of soil erosion

The rhizomes of cogongrass, which was the dominant species in the "two cuttings per year" plots, extended to within a depth of 45 cm, and 80 % of all rhizomes extended to within to a depth of 10 cm. Thus, Ezaki [3] reported that cogongrass was as good, or better than Japanese lawn grass ,at preventing surface erosion. This suggests that the cogongrass type can be very useful as vegetation on embankment slopes, in spite of the fact that cogongrass is an aggressive weed.

2.Environmental function

In light of recent advances in ecological understanding, urban river management involves more than flood control and water resources. It also involves appreciating the river's environmental role. This role has several functions: First, a high species diversity provides biotopes for grassland insects. Second, the cogongrass type also is an important part of the traditional rural landscape. The scenery changes season by season – from the flowering of many component species, to the red leaves of cogongrass in winter, not to mention the seasonal changes brought about by therophytes. Third, thus grassland is expected be used as an amenity. Cogongrass type "two cuttings per year" is useful in this respect.

3.Sustainable grassland under the two cuttings per year

In Japan, there are two flood seasons, the rainy and typhoon seasons. As the surface of embankment slopes must be observed before these flood seasons from the viewpoint of disaster prevention, the cuttings should be done at least twice a year. But, it is difficult to cut more than three times a year for economic reasons. For example, 140 million yen, 46% of all maintenance expenses of the Ina River in Hyogo consists of the expense of cutting even at only two cuttings per year. For these reasons, the vegetation on the embankment slopes is generally cut twice a year. Cogongrass type is often seen on the embankments which received maintenance of two cuttings per year [4] . This supports the results of our cutting test. The present condition of embankment slopes in Japan suggests that cogongrass is a useful plant for revegetation there, because the cogongrass type can be maintained by two cuttings per year.

4.Practical application

We may, from what has been said above, reasonably conclude that cogongrass type is a suitable grassland on the embankment slopes. Moreover in the present time when the introduction of greenery is desired in urban areas, we are ready to consider that cogongrass type is suitable for parks, too. Both revegetation methods, planting and seeding, are only being tested on small areas. Further, the development of a technique for practical application is needed.

Acknowledgements: Thanks are due to Robert J. Bloemeke for reading the entire text in its original form. And I wish to thank the staffs of Ina River Work office Kinki Regional Construction Bureau Ministry of Construction for useful information.

References

1) ASAMI, K., H. AKAMATSU, T. HATTORI and H. TSUJI (1994): Ecological studies on management of grassland vegetation on the embankment slope III. Effect of cutting on the embankment vegetation at the Naka River. Humans and Nature. 4,81−97.

2) ASAMI, K., T. HATTORI, H. AKAMATSU, K. WADA and S. KATO (1994): Ecological studies on management of grassland vegetation on the embankment slope I. Effect of cutting on the embankment vegetation at the Niyodo River. Humans and Nature. 3,85−98.

3) EZAKI, T., M. FUJIHISA and Y. IMON (1992): Utilization of kind of weeds on the slope of river banks in relation to disaster prevention. Weed Research, Japan. 37,239−247.
4) ITO, M. (1982): Weeds and their management in non−crop land. Weed research, Japan. 27,162−175.
5) KODATE, S., K. ASAMI and T. HATTORI (1994): Ecological studies on management of grassland vegetation on the embankment slope II. Effects of the cutting on the embankment vegetation at the Ina River. Humans and Nature. 3,99−115.
6) KONDOH, M. (1991): The latest handbook of methods and materials of revegetation. Soft science corporation. 159−180.

Table 1. Cutting frequency and cutting month

cutting frequency	cutting month		
(study site)	(A)	(B)	(C)
No cutting	-	-	-
1 cutting per every two years	Aug.	*	Jun.
1 cutting per year	Jun. ~ Jul.	Aug.	Jun.
2 cuttings per year	Jun. ~ Jul.and Oct. ~ Dec.	Aug. and Sept. ~ Oct.	Jun. and Oct.
3 cuttings per year	*	Jun. and Aug. and Sept. ~ Oct.	*

Study sites (A - C) correspond to those in Fig.1. Asterisk means no plot in the study site.

Table 2. The relationships between cutting frequency and ecological characteristics four years after starting the cutting test.

cutting frequency	type of community	Number of study sites	Height in Aug.	Variety of species	Diversity of species (1/d)	Seasonal aspect by appearance of therophytes
No cutting	eulaliagrass type	3	1.50m	poor	low	obscure
1 cutting every two years	eulaliagrass type or [cogongrass] type	2	1.30m	poor	low	obscure
1 cutting per year	eulaliagrass type or cogongrass type	3	0.75m	medium	medium	obvious
2 cuttings per year	cogongrass type or [eulaliagrass] - [cogongrass] type	3	0.50m	abundance	high	obvious
3 cuttings per year	Japanese lawn grass - cogongrass type	1	0.35m	poor	low	obvious

Table 3. Summary of seven experimental fields planted with Cogongrass

Study site	A	A	E	E	D	D	F
Date of planting	Jun.1988	Jul.1989	Sep.1989	Jul.1991	Jun.1989	Jun.1991	Jun.1993
Field size (m^2)	10	10	3	1	3	6	30
Planting density (/ m^2)	60 ~ 100	60	60	60	60	60	50
Initial maintenance	Cutting	Watering, Cutting	Watering	Watering	Watering	Watering	Watering
Initial phase (grassland type)	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass
Present phase (grassland type)	Weed	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass

Study sites (A -C) correspond tu those in Fig.1.

Table 4. Summary of seven experimental fields seeded with Cogongrass

Study site	A	A	E	E	D	D	F
Date of seeding	Jun. 1988	Jul. 1989	Sep. 1989	Jul. 1990	Aug. 1989	Jun. 1991	Jun. 1993
Field size (㎡)	300	500	100	125	24	24	200
Seeding density (/ ㎡)	10000	10000	7500	12000	10000	10000	5900
Initial maintenance	Cutting	Watering, Cutting		Watering	Watering		Watering, Cutting
Number of species in mixed seeds	6 ~ 33	5	1	1	1	1	11
Initial phase (grassland type)	Weed	Weed	Weed	Weed	Weed	Cogongrass	Cogongrass
Present phase (grassland type)	Weed	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass	Cogongrass

Study sites (A -C) correspond tu those in Fig.1.

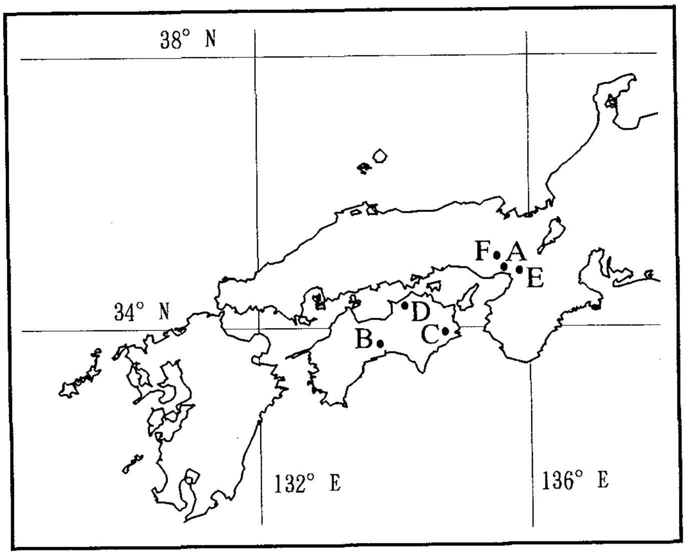


Fig. 1 The locations of the study sites. A : The Ina River in Hyogo Pref., B : The Niyodo River in Kochi Pref., C : The Naka River in Tokushima Pref., D : The Doki River in Kagawa Pref., E : The Yodo River in Osaka Pref., F : Sanda City in Hyogo Pref.

Germination characteristics and Population Management of <u>Aster</u> <u>Ageratoides</u> subsp. <u>ovatus</u> for Landscaping with Wildflowers

T. Kondo*
Fukui Agricultural Experiment Station
52-22 Ryo-machi Henguri, Fukui 910, Japan

<u>Abstract.</u>
With the increasing interest in nature, the value of wildflowers as landscaping material is being reconsidered. The germination characteristics and population management of <u>Aster ageratoides</u> subsp. <u>ovatus</u>, the population of which is sometimes observed along footpaths, were studied. In laboratory tests using petri dishes, seeds showed good germination at 20-25℃ in darkness. Under light, they showed good germination even at 15℃ or 30℃. The germination percentages of seeds stratified over one month at 3℃ were almost 100 % in 10-30℃. The germination period of the stratified seeds was shortened. Seeds sown from November to January in pots in the field overwintered in the cold and moist winter and germinated in February or March during which the temperature is relatively low. Seeds sown from April to October showed a high germination within two weeks. The behavior of germination in the field corresponded to germination characteristics in laboratory tests. When seeds were sown from April to June in the field, flowering and seed set occurred in the autumn of that year. The seeds sown after August produced flowering plants in the autumn of the next year. In cutting experiments using a population made with container grown plants, sufficient flowering was maintained and the height of sward was controlled to 20 cm by cutting twice a year, in early June and in early August. Cutting in early September, on the other hand, induced poor flowering.

<u>Key words.</u> <u>Aster Ageratoides</u> subsp. <u>ovatus</u>, Germination, Population management, Landscaping, Wildflowers.

Introduction

Recent changes in agriculture have resulted in the ecological poverty of the natural environment in rural districts where there is a treasure house of various wildflowers. On the other hand, with the increasing interest in nature, the value of wildflowers as landscaping material is being reconsidered, and technical guidelines on their introduction into green areas are required.

<u>Aster</u> <u>ageratoides</u> Turcz. subsp. <u>ovatus</u> (Fr. et Sav.) is a typical Japanese wild flower. It is sometimes observed along footpaths coexisting with other weeds for many years. The purpose of this investigation is to study its germination characteristics and its reaction to cutting, and to show technical methods for the establishment and management of the population.

Material and methods

Effects of light and temperature on germination

Seeds with a pappus were collected by hand from the natural population in Fukui city in December 1987. Seeds were dried indoors for 10 days, removed from the pappus by hand and selected by being winnowed. Germination tests were carried out using fresh seeds at five constant (10,15,20,25 and 30℃) temperatures, and at a 12-h photoperiod or in continuous darkness except for daily investigation. The light source was 20-W cool-white fluorescent tubes, and irradiance at the seed level was about 3 klx. Seeds were placed on two layers of moistened (Whatman #2) filter paper with four replicate dishes of 25 seeds per treatment. The tests lasted for 40 days when most germination finished.

Effects of stratification on germination

Some seeds were stored in moisture-proof plastic containers with silica gel at 3℃(dry storage). Other seeds were put between sheets of moist gauze and stored in the dark at 3℃ (stratification).

Germination tests were done after 1, 3, and 6 months of storage. The seed source and conditions of germination were as described above. Mean days to germination[4)] was used as the index of germination speed.

Germination behavior in the field

Seeds were sown at the middle of every month from December 1987 to February 1988 in outdoor pots. The pots were 1/5000 Wagner pots and were filled with sand soil. Three replicate pots of 100 seeds were used. The seeds were covered only lightly with soil. Germination was investigated every two or three days. Watering was done when the soil surface was dry.

Sowing time and following seasonal changes

Seeds were sown in the middle of April, June, August and October 1989 in the experimental field. 100g of slow release fertilizer (N:P:K=3:20:3) was applied per m^2 before sowing. 150 seeds were sown in a plot (50×50 cm). Germination , flowering, seed setting and other seasonal changes were observed till the end of November 1990. Watering was done two weeks after sowing, but watering or weeding were not done afterwards.

Cutting

The experimental field was soil dressed with sandy soil in 1986. Application of 65g of slow release fertilizer (N:P:K=3:20:3) per m^2 was done in the field, and seven experimental plots (1×1m) were set on May 25, 1987. 25 container grown plants were transplanted to each plot at intervals of 20 cm on June 2, 1987. Watering was done two weeks after sowing, but watering or weeding were not done afterwards.

On September 1 and December 9 1987, plant height and the number of stems were measured. Cutting was performed from 1988 to 1989. In 1988, after cutting in October flowering did not occur. Therefore, in 1989, the cutting time was changed, as shown in Table 1. These cuttings were done at the beginning of each month, and were carried out with a bush cutter and at a height of about 3 cm. In addition, early in May 1988 and 1989, experimental plots were cut to remove their dead stems.

At the beginning of each month, plant height and the number of stems were measured. The flowering state was observed every 5 days. The top biomass (dried at 105℃ and for 24 hours) of *A. ageratoides* subsp. *ovatus* and weeds was measured at the cutting time.

Table 1 Cutting time

1988		1989
Non-cutting	&	Non-cutting
June	&	June
July	&	July
June and August	&	June and August
June and October	&	June and September
July and October	&	July and September
June, August and October	&	June and August

Results and Discussion

Effects of light and temperature on germination

The germination percentages in darkness were about 80% at 20-25℃. 60% germinated at 15℃ within 40 days. Light conditions caused high germination

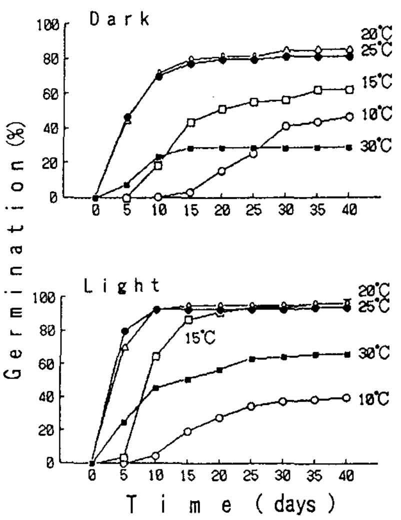


Fig. 1 Effects of light and temperature on the germination of *A. ageratoides* subsp. *ovatus* fresh seeds.

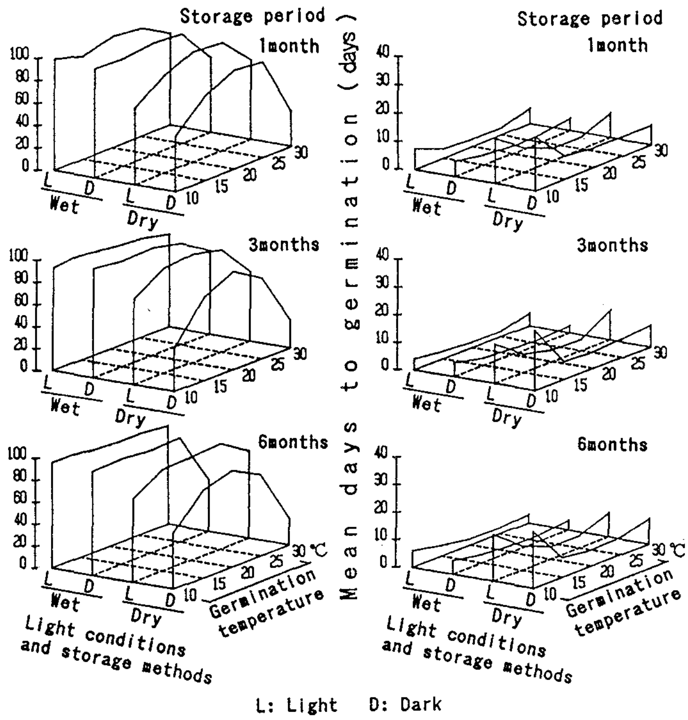


Fig. 2 Effects of stratification on the germination of *A. ageratoides* subsp. *ovatus* seeds. 40 days after sowing.

and a reduction of mean days to germination at 15-30℃ as compared to germination in dark conditions (Fig.1).

KONDO and KASAHARA[1] concluded that germination of A. ageratoides subsp. ovatus seeds was not much affected by light or dark conditions because 80% of seeds germinated in light and 62% of seeds germinated in dark, respectively, at 25℃ 40 days after sowing. While results in this paper clarified that germination at 20-25℃ temperature was not affected by light or dark conditions, germination at a higher or a lower temperature than at 20-25℃ was promoted in light conditions.

Effects of stratification on germination

Seeds stored in dry conditions increased their germination somewhat in light conditions at 10 and 30℃ in comparison to fresh seeds, but in other germination conditions, seeds stored in dry conditions almost only kept to germination of the fresh seeds regardless of the length of storage(Fig.2). On the contrary, seeds stratified for over one month germinated about 100% at 10-30℃ in light and dark conditions, and mean time to germination was shortened considerably.

The marked effects of stratification and the previous optimum temperature for germination suggest that seeds dispersed naturally in December in the field hardly germinated within that year, and sprout in early spring after a cold and wet winter.

Germination behaviour in the field

Seeds sown from April to October showed a high germination percentage within two weeks (Fig.3). Seeds sown from November to February in the field did not germinate within two weeks. After overwintering in the cold and moist winter, seeds germinated in February or March during which the temperature is relatively low.

This germination behaviour in the field supported the previous suggestion in the laboratory tests.

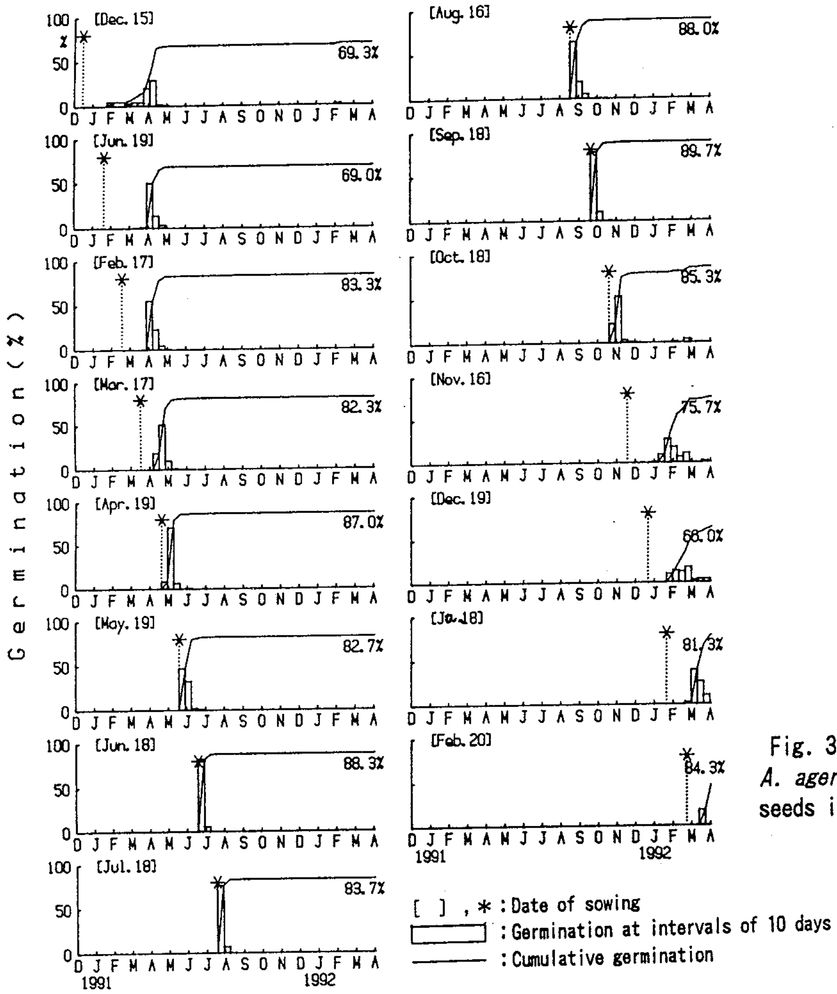


Fig. 3 Germination behavior of *A. ageratoides* subsp. *ovatus* seeds in the field.

Sowing time and following seasonal changes

When seeds were sown in April and June in the field, flowering and seed set occurred in the autumn of that year. Sowing in August resulted in flowering in autumn of next year. When seeds were sown in October, they germinated soon, but all of the seedling died and disappeared because of frost injury (data not shown).

Effects of cutting on plant height and number of stems

Plant height in non-cutting treatment increased from 4 cm at planting to about 70 cm in the autumn two and three years after planting (Fig.4). Cutting in June inhibited the plant height to 40 cm at the term of flowering. Cutting in July controlled the height to 30 cm at the term of flowering. Cutting twice a year in June and August reduced it to 20 cm.

25 stems per m^2 increased to about 300/m^2 in non-cutting treatment two and three years after planting. The number was about 14 times that at the time of planting (Fig.5). Cutting once a year increased the number of stems to about 1.5 times that of the number of stems produced in non-cutting treatment. Cutting twice or three times a year did not increase the number of stems compared with cutting once a year because cutting was done before the top had reproduced sufficiently.

Effects of cutting on flowering

Flowering occurred in the autumn of the planting year.Fig.6 shows flowering

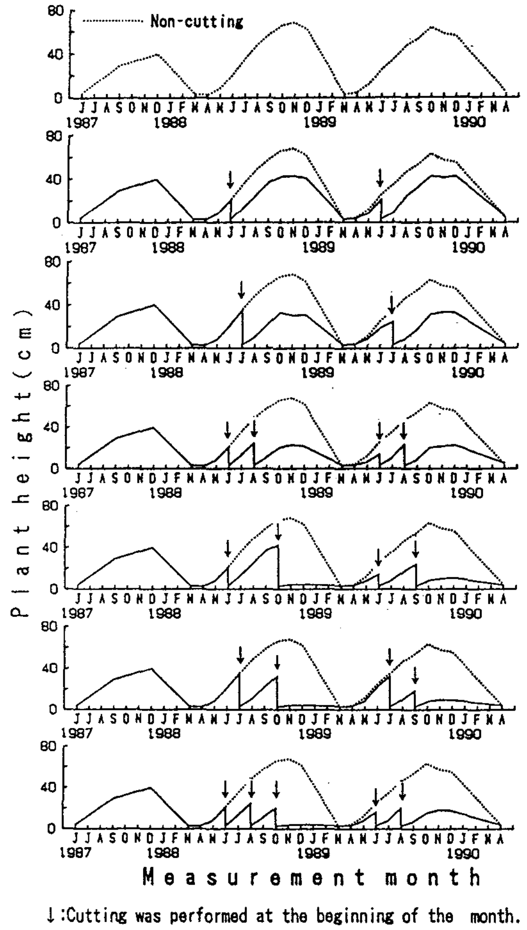


Fig. 4 Effects of cutting on the plant height of *A. ageratoides* subsp. *ovatus* population.

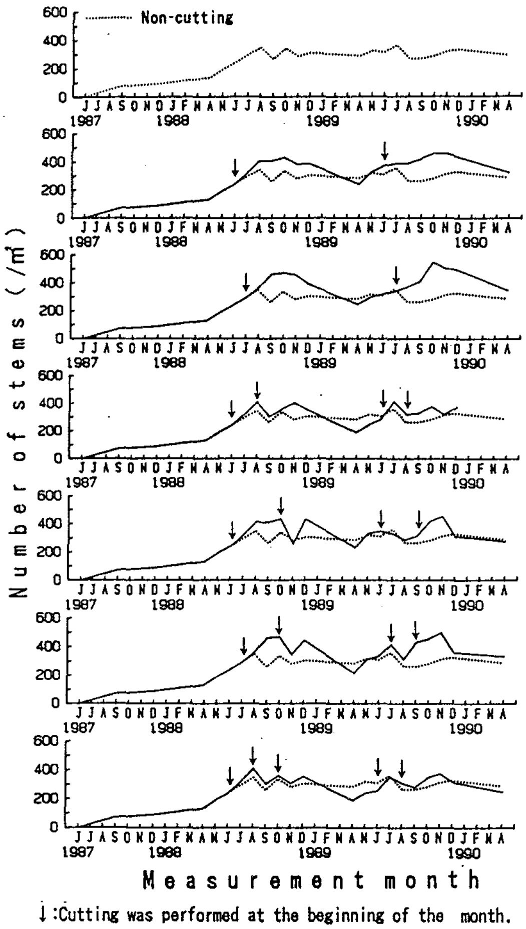


Fig. 5 Effects of cutting on the number of the stems of *A. ageratoides* subsp. *ovatus*.

state of three years after planting. In non-cutting treatment, flowering occurred at the end of September and continued to the middle of November with seed setting. Cutting once a year in June or in July delayed the flowering period by 5 days or 15 days respectively compared with non-cutting treatment, but the flowering state were satisfactory. Cutting twice a year in June and August delayed the flowering period and somewhat reduced the number of flowers compared with cutting once a year. This cutting inhibited the plant height to 20 cm and created a beautiful flowering sward. Cutting in September, on the other hand, induced a poor flowering state. Flowering was not caused after cutting in October.

Weeds

As the cutting frequency increased, the weeds which are more resistant to cutting than A. ageratoides subsp. ovatus invade the population. Fig.7 shows the relation between percentages of invading weeds per total top biomass and top production of A. ageratoides subsp. ovatus per one month during June to October when production was lively. It is seen from this figure that weeds inhibit the production of A. ageratoides subsp. ovatus and the top production of A. ageratoides subsp. ovatus was reduced to under half when the percentages of invading weed become more than 10%.

Establishment and management of the population

Consideration of the above results in conjunction with the previous reports can summarize the methods of establishment and managing the population as

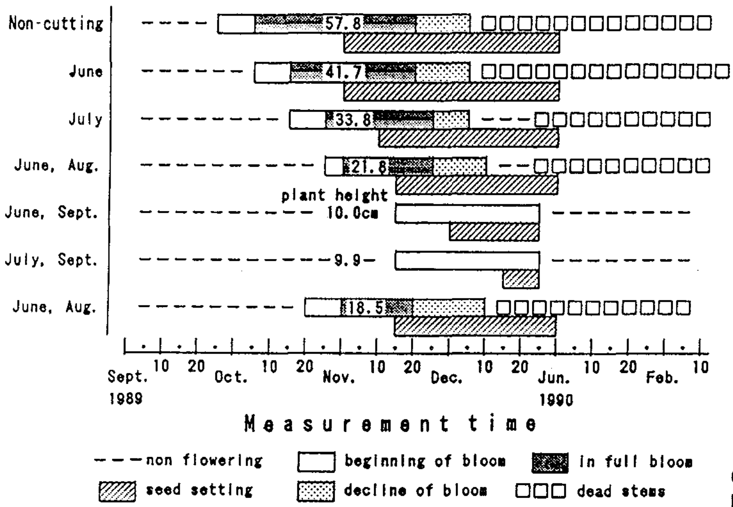


Fig. 6 Effects of cutting on flowering of *A. ageratoides* subsp. *ovatus* population.

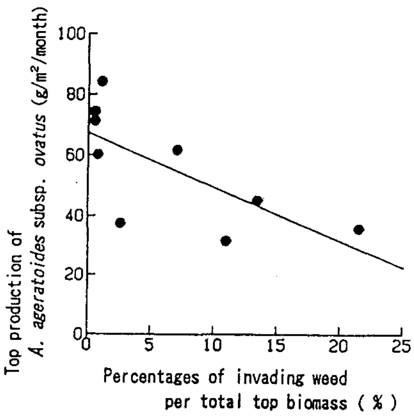


Fig. 7 Relation between percentage of invading weeds per total top biomass and top production of *A. ageratoides* subsp. *ovatus* per m² for a month from June to October at the time of cutting.

follows.

Germination characteristics are important in creating population not only with pot grown plants but also by sowing. Suitable depth for the soil cover is 5 mm, but 10 mm of soil cover reduces the germination markedly[2]. Seeds keep their germinability at least for one year, if seeds are stored in dry conditions and at a constant temperature of 10-30℃[3]. Seedlings emerge within two weeks of sowing except in winter. When seeds are sown during April to June in the field, flowering occurs in the autumn of that year.

When the population is not cut and is left alone, plants have a number of flowers. Plant height becomes so high that the population scene becomes unsightly. Therefore, cutting is needed to control plant height. Cutting twice a year in early June and early August controls the plant height to 20 cm and keeps a sufficient number of flowers. Cutting after September, on the other hand, induces a poor flowering state. Moreover, cutting in winter or early in the spring was needed to remove dead stems. As the weeds increase, top production of A. ageratoides subsp. ovatus decreases. Therefore, to maintain the population for a long time, cutting to control weeds and weeding before the introduction of A. ageratoides subsp. ovatus may be important.

References

1)KONDO,M. and KASAHARA,Y.,1941,Study on the germination of weeds 1. Effect of light and alternating temperature on the germination, Nougaku kenkyu, 32, 357-397.(Japanese)

2)KONDO,T. ,MAENAKA,H. and TAKAHASHI,R.,1991, Effects of Soil Cover on the Seedling Emergence of Several Wild Flowers, Journal of the Japanese Institute of Landscape Architects,54(5),149-154. (Japanese, English summary)

3)KONDO,T. ,MAENAKA,H. and TAKAHASHI,R.,1992, Propagation and Vegetational Management of Wildflowers - Germination, Cutting Propagation, and Frequency and Timing of Mowing for Extending the Flowering Season of A. ageratoides subsp. ovatus Kitam., Journal of the Japanese?,17,193-202.(Japanese, English summary)

4)NICHOLS,M.A. and HEYDECKER,W.,1968, Two approaches to the study of germination data, Proc.Int.Seed Test. Ass.,33(3),531-540.

Growing Pineapple by No-tillage Techniques and Its Impact on Weed Status

C. Lao-sinwatthana and U. Suwunnamek

Department of Agronomy, Kasetsart University, Bangkok 10900, Thailand

Abstract. Techniques have been initiated to save the high cost and the long soil preparation process for intercycle planting and also to solve soil erosion problem. No-tillage study on pineapple (*Ananas comosus* (L.) Merr.) was conducted comparing with the conventional tillage in 4 periods of the year. Pineapple crowns and suckers were planted between the stumps of old plants which had been killed by herbicide and slashed. It was found that no-tillage plants grown during the high rainfall period of wet season provided better crop growth and yield. The plants tended to grow slower than the conventional and plants from suckers grew better than those from crowns. No-tillage sucker plants grown at an appropriate time produced fruit yield quite comparable with the conventional. The mulching effect of crop residue caused a considerable reduction of weed growth in no-tillage plots without negative effect on crop growth through 12 months of age.

Keywords : Pineapple, crowns and suckers, no-tillage techniques, weed dynamics, intercycle planting, mulching effect.

Introduction

The process of standard soil preparation for intercycle planting of pineapple (*Ananas comosus* (L.) Merr.) requires many times of heavy-disked plough to knockdown the old plants, crush and chop them into the soil. The process usually takes 5 to 8 months to finish (1). The problem of soil erosion and surface run-off is also another reason. Advantages and disadvantages of no-tillage farming were described by Young, Jr. (5). Certain varieties of pineapple such as Queen and its sub-varieties have been grown no-tillage in moist peat soil in Malaysia for a long time. Earlier, Smooth Cayenne, the present variety for commercial canning, was also tried in Thailand but the report was not disclosed to the public. No-tillage practice looks more possible after the report that certain pyridinyl herbicides were quite effective for knockdown of the old pineapple plants (2). Good succcess of the practice was reported both under irrigated and unirrigated conditions (4). Still, there are some factors to be studied for industrial production.

Objectives of this no-tillage study on pineapple are :1) to find out the suitable planting date, 2) to compare the planting material to be used, 3) to study the change of weed density and species, and 4) to study on weed competition.

Materials and Methods

The study consisted of 3 experiments, i.e., growing no-tillage pineapple at varying dates, effect of no-tillage practice on weed status, and the effect of weed competition.

Effect of planting date and planting material. The study consisted of 4 experiments, i.e., planting in mid-wet season (Aug. 24, '92), late wet season (Oct. 26, '92), mid-dry season (Feb. 19, '93) and early wet season (May 23, '93). Experiment included no-tillage and conventional tillage plots. Crowns and suckers of Smooth Cayenne pineapple sub-var. Pattavia were planted separtaely in sub-plot size 16 x 25 m^2. No-tillage plots were prepared by killing the old plants with fluroxypyr 2.25 kg ai/ha at the volume of 2,000 L. Five days later all plants were slashed at ground level. Crown and sucker size No. 2 (250 to 350 g) were planted two weeks later in the same line between the old stumps with the same spacings (25 x 60 x 70 cm) numbering 61,500 plants/ha. All maintenance practices were employed similarly with the conventional. Conventional tillage plots were prepared by modifying the standard method. Old plants were slashed at ground line. After 3 weeks the plant residue was ploughed under by using heavy disked plough. A month later the soil was reploughed and also repeated another time a month after that. The soil was later on harrowed twice until the soil broken and loosened enough for planting. Ridges 60 cm wide and 15 cm high were made 70 cm apart. Plant materials were planted two lines on the ridge spaced 25 cm in the line. Crop maintenance was undertaken normally (3).

Plant growth was assessed at 3, 5, 7, 9 and 11 months after planting. Six plants (2 from the small sized, 2 from medium, and 2 from large) from each treatment were uprooted, roots cut, cleaned and weighed. Normally, when plants reach at least 2.3 kg of weight (about 12 months of age) they are forced to flower and fruits will be ready for harvest about 5 months later. Six areas (with 100 fruits each) in a treatment were harvested and assessed. Statistic difference was determined by the use of standard errors.

Effect on weed species and density. The study consisted of 2 experiments, i.e, one conducted in mid-dry season (March 6, '93) and another in mid-wet season (July 20, '93). Experiment composed of no-tillage and conventional tillage plots sized 10 x 21 m for each. Soil preparation, planting, and crop maintenance were similar to those in the previous experiment. Four areas of the size 1.3 x 1 m (1 two-line bed wide and 1 m long) in each treatment were randomly fixed. All weed species in an area were assessed at 2, 4, and 6 months after planting. They were uprooted, classified, and counted. Shoot dry weight of the weed by group was also determined. After each assessment all plots were completely hand-weeded. Values were statistically analyzed.

Effect of weed competition. Experiment consisted of 5 treatments, i.e, hand-weeded all through after 2, 4, 6, 8, and 12 months of planting by no-tillage method. Plot size was 6.5 x 7 m (5 two-line bed wide and 7 m long) with 3 replications. Plant growth was assessed at 3, 5, 7, 9, and 11 months after planting and also at forcing time. Statistic difference was determined by Ducan's Multiple Range Test.

Results and Discussion

Effect of planting date and planting material. Growth of pineapple plants under no-tillage and conventional tillage conditions was shown in Figures 1 to 4. No-tillage plants grown from suckers in mid-wet and late wet seasons seem to produce growth almost comparable to those of the conventional (Figures 1 and 2). At forcing growth of sucker-grown of both and crown-grown conventional was about the same. No-tillage plants from crowns grew much less than all others. And this is in the same way with mid-dry season and early wet season experiments (Figures 3 and 4). The reason is probably due to the crown base is too short and can be inserted into the soil shallower (only about 5 cm) and easily dislodged, meanwhile sucker planted deeper (10 to 15 cm). So, under no-tillage conditions sucker is more preferable and also the soil around must be packed with it. Growth of no-tillage plants grown in mid-dry season (Figure 3) was even less than those under conventional conditions and made them need 2 1/2 more months for forcing. No-tillage growing in early wet season was found to be the best timing of all according to the growth shown in Figure 4.

Considering the effect on fruit yield indicated in Table 1 it was found that the trend is in the same way as plant growth. No-tillage crown-grown plants comparatively produced the lowest fruit yield among others in all 4 experiments. Sucker-grown plants, especially conducted in early or late wet season provided yield quite comparable with those of the conventional. Unfortunatily, during mid-wet season this year rainfall was suspended for several weeks before and after planting.

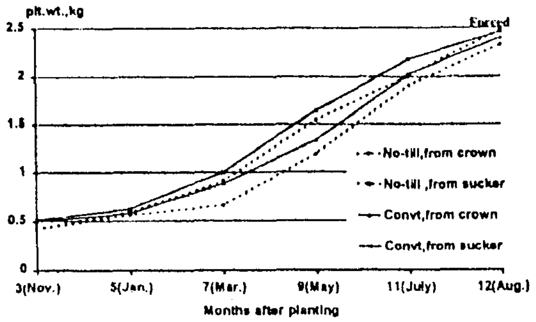


Figure 1. Growth of pineapple planted in mid -wet season (Aug.24,1992).

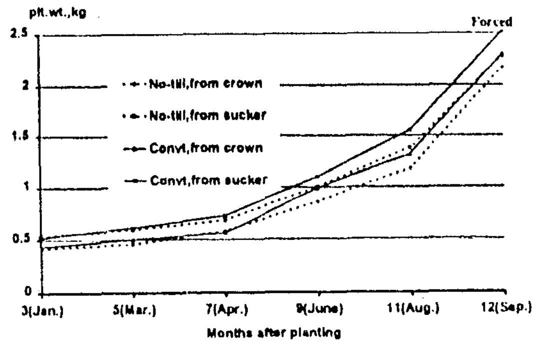


Figure 2. Growth of pineapple planted in late wet season(Oct.26,1993).

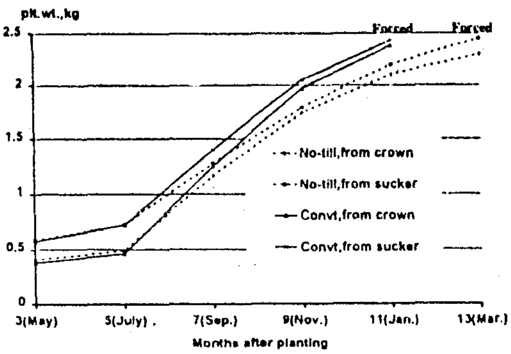


Figure 3. Growth of pineapple planted in mid-dry season(Feb.19,1993).

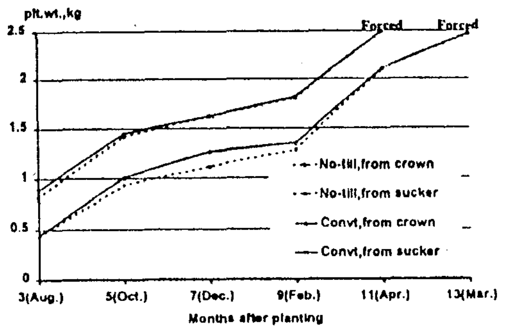


Figure 4. Growth of pineapple planted in early wet season(May 23,1993).

Table 1. Fruit yields of pineapple planted by no-tillage and conventional tillage mothods at varying dates.

Planting date	No-tillage		Conventional tillage	
	Crown-grown	Sucker-grown	Crown-grown	Sucker-grown
	(t/ha)			
Mid-wet season	61.81 ± 0.81	70.19 ± 3.56	77.38 ± 2.63	75.63 ± 6.07
Late wet season	75.94 ± 1.31	85.00 ± 1.94	81.31 ± 1.44	86.19 ± 5.94
Mid-dry season	78.75[1/] ± 1.88	87.38[1/] ± 2.50	78.63 ± 1.56	86.50 ± 3.75
Early wet season	82.06 ± 1.69	84.69[2/] ± 0.69	88.94 ± 2.00	87.38[2/] ± 1.56
Average	74.64 ± 1.42	81.81 ± 2.17	81.57 ± 1.91	83.93 ± 4.33

1/ Forced to flowering 2 1/2 months later than those in the conventional.

2/ Forced to flowering a month earlier than the crown-grown plants.

So for material used, under conventional conditions there is no difference between suckers and crowns, but there is under no-tillage conditions. Sucker-grown plants by no-tillage method if under favorable conditions at planting time, e.g., early or late wet season which is the period of frequent and high rainfall can produce fruit yield almost the same as those in the conventional. Normally, during repeated rainfall period it is not appropriate for planting pineapple.

Effect on weed species and density. Considering the results from 2 experiments (Table 2), weed density in no-tillage plot was so small, about 3 to 4% of those in the conventional (about 1,000 plt/1.3 m^2) their growth was healthier (dry weight about 20% of the conventional) due to the less competition. In no-tillage plot, and broadleaves were found outnumber grasses (more than 50 %) which conversely were many times more than broadleaves in the conventional. It was observed that most weeds in no-tillage plots emerged from disturbed soil at the plant base. Crop residue of slashed leaves and parts of stem of old plants at least 130 t/ha covering the area prevented germination of a large number of annual weeds all through 6 months after planting (Tables 3). So, by this technique regular hand-weeding (about every 3 months) can be possible in small holder farms. For industrial production one application of ametryn plus bromacil at 6 months after planting is enough to provide a good weed control until harvest.

Table 2. Total count and dry weight of weeds during 6 months after planting pineapple no-tillage and conventional tillage in dry and wet season.

	Total weed count				Shoot dry weight			
	Dry season		Wet season		Dry season		Wet season	
Weed group	No-tillage	Convtn'l	No-tillage	Convtn'l	No-tillage	Convtn'l	No-tillage	Convtn'l
	(no./1.3 x 1 m^2)				(g/1.3 x 1 m^2)			
Broadleaves	21b	40a	20b	137a	309b	392a	127b	311a
Grasses	14b	1,084a	15b	692a	67b	1,472a	95b	714a
Total	35	1,124	35	829	376	1,864	222	1,025
As % of Convtn'l	3.1		4.2		20.2		21.7	

Value within the same weed group and season of assessment followed by the same letter did not differ significantly at the P=0.05 level as measured by LSD test.

The effect of weed competition. Crop growth assessment by weighing the plant already having been exposed to weed competition for 2, 4, 6, 8, and 12 months after planting found that there was no significant difference in growth at forcing time (Table 4). This is due to the

Table 3. Accumulated weed count for 6 months in no-tillage and conventional tillage pineapple planted in dry and wet seasons.

Weed species	Dry season		Wet season	
	No-tillage	Convtn'l	No-tillage	Convtn'l
	(no./1.3x1 m^2)			
Euph. het.	1	2	3	56
Amar. vir.	9	16	..	..
Cocc. gran.	4	1	4	1
Borr. ala.	1	10	6	41
Cleo. ruti.	4	10	7	39
Ipom. obsc.	1	0	..	..
Comm. beng.	1	1	..	..
Penn. poly.	0	8	4	16
Echi. col.	1	733	6	554
Brac. dist.	7	146	2	62
Dact. aeg.	3	93	3	60
Eleu. ind.	1	84	..	..
Lept. chin.	7	20	..	..
Broadleaves	21	40	20	137
Grasses	14	1,084	15	692

Euphorbia heteropylla L. *Ipomoea obscura* (L.) Ker-Gawl. *Brachiaria distachya* (L.) Stapf
Amaranthus viridis L. *Commelina benghalensis* L. *Dactyloctenium aegyptium* (L.) Willd.
Coccinia grandis L. *Pennistum polystachyon* (L.) Schult. *Eleusine indica* (L.) Gaertn.
Borreria alata (Aubl.) DC. *Echinochloa colona* (L.) Link. *Leptochloa chinensis* (L.) Nees
Cleome rutidosperma DC.

considerable reduction of weed population in no-tillage plots as in the preceding experiment. Competition for 2 and 12 months after planting were respectively regarded as weeded and unweeded controls. Even though crop plants were not affected by weeds, to facilitate other field practices they still must be controlled, especially before forcing. Normally after forcing weed control is not employed, especially by herbicide treatment.

In conclusion growing pineapple by no-tillage techniques is worth trying. Lately, we also found that glyphosate (5.625 kg ae plus $(NH_4)_2SO_4$ 25 kg in water 2,000 L/ha) or

Tabel 4. Growth of pineapple plants as affected by weed competition for varying periods after no-tillage planting.

Competition period months after planting	Plant weight, months after planting 3	5	7	9	11	At forcing
	(kg)					
2 (Control-weeded)	0.43a[1/]	0.51b	0.80a	1.19b	2.30ab	2.49a
4	0.40a	0.60a	0.80a	1.27a	2.43a	2.53a
6	0.41a	0.51b	0.84a	1.18b	2.23b	2.48a
8	0.41a	0.53b	0.82a	1.30a	2.32ab	2.50a
12 (Control-unweeded)	0.42a	0.52b	0.79a	1.21ab	2..25b	2.51a

[1/] Values in the column followed by the same letter are not significantly different at 5 % level by Duncan's Multiple Range Test.

paraquat (3.75 kg ion in water 4,000 L/ha) can be used for killing the old plants(unpublished, data not shown).Slashing should be made 5 days after application for paraquat and 10 days for glyphosate. One problem is that the cost of planting by hand is about 30 % higher. Whether this is justified or not depends on the situation.

Acknowledgements : The authors wish to express sincere gratitude and appreciation to Kasetsart University and Siam Agro-Industry (Pineapple and Others) Co. Ltd.(SAICO) for the financial support under Project 402/346 .

References

1.Collins, I.L. 1968.Pineapple. Botany, Cultivation and Utilization. Leonard Hill Books, London. p. 142.

2.Loyritthiwudthikrai, C. and U. Suwunnamek. 1990. Application of certain pyridiny herhicides to assist in the intercycle knockdown operation of pineappl. Proc Tro. Weed Sci. Conf. 3 : 473-478.

3.Siriphat, S. 1994. Growing pineapple in the SAICO styl Proc. the First Thai Pineapple Symposium 1 (2) : 20-32 (in Thai)

4.Suwunnamek, U., S. Ruaeng-iam, S. Saengchinda, and C. Lao-sinwatthana. 1994. Concept and possibility of growing pineapple by no-tillage techniques. Proc. the First Thai Pineapple Symposium 1 (2) : 1-9. (in Thai)

5.Young, Jr., H.M. 1982. No-tillage Farming. No-tillage Farmer, Inc., Brookfield, Wisc. pp 39-68.

WEED INFESTATION IN RAPE FIELD USING DIFFERENT CULTURAL PRACTICES AND HERBICIDES

Tang Hong Yuan, Sheng Guo Hui, Wang Xue E, Si Xin

Shanghai Academy of Agricultural Science, Shanghai, 201106 China

A field test showed that weed biomass in 0.11 spuare meter of no- till transplanted rape, direct- seeded and till transplanted rape was 42.5g, 85g, and 540g; 13.8g, 17.5g, and 365g; and 11.3g, 34.1g, and 311.8g on 30 Feb., 11 Mar., 5 Apr. 1993, respectively. The ratio of crop and weeds was: 1:3.7, 1:1.2, 1:3.4; 1:4.9, 1:6.3, 1:6.4, and 1:1.4, 1:0.2, 1:1.1. In the no-till transplanted rape field, the weeds germinated before the crop was planted and dominated the crop. In the direct- seeded rape field, they germinated at the same time as the crop, and were equally strong. while the till transplanted rape, the weeds were samll and weaker than the crop. Therefore, till transplaning was adopted as the traditional weed control method. Acetchlor, Traflan, Devrinol, and Stomp were used to control grass and some broad-leaf weeds. Devrinol and stomp can be used pre-emergence in direct-seeded rape.
Key words : Weed ,Cultural practice,Herbicide.

INTRODUCTION

The rape is one of most important oil crop in China. There Tow kinds of cultural practices are direct- seeding and transplanting. The labourers shifted from agricultural production to enterprises and industries in countray was happened in China, particularly in east-south sea coast area. Because of the labour shortage, the no till cultrual practice was adopted in rape production recentlly. The weed infestation was more serious than before. A surveying of chariteristic of weed occurrence under different cultural practices and weed control were tested and several herbicides were evaluated in this experiment.

MATHODS AND MATERIALS

The Acetchlor, Traflan, Deverinol, Stomp, Sethoxydin, and Galtak were applied in direct-seeded, and tranplanted rape small plot fields in pre-emerge and post-emerge stage. The experiment was laidout in a complete randomized block design with 3 replicates. Each plot is 20 sqare meter. Weed were sampled in o. 11 sqare meter. and 10 rape plants were weighed in 30. Jan., 30. Fab., 11. Mar. and 5. Apri. 1993.

RESULTS AND DISCUSSION

1, The cultrual practice weed management

The test showed that weed biomass in o. 11 sqare meter of no till transplanted rape, direct-seeded and till trnsplanted rape was 42. 5g, 85g, and 540g; 13. 8g, 17. 5, and 365g; 11. 3g, 34. 1g and 311. 8g on 30. Jan., 11. Mar., 5. Apri. 1993 respectively. The ratio of crop and weeds was 1: 3. 7, 1: 1. 2 and 1: 3. 4; 1: 4. 9, 1: 6. 3 and 1: 6. 4; 1: 1. 4, 1: 0. 2, and 1: 1. 1 respectively. So the till tranplanted rape was adopted as the traditional weed management in China. (fig 1, 2,) . The data indicated that some weeds emerged before the rape transplanted in no till fields, even them, most rape plants are biger than weeds, but weeds are growing quicker than crops, they dominated the rape at last. The weeds and crops are emergeing almost same time in direct-seeded rape, but weeds are growing quicker and stronger than rapes, they dominated crops as usul. So, weed infestation is serious. The weeds are emerging after rape transplanted about 10 days in till transplanting rape fields. The rape plants are biger and stronger than weeds, mostly, the rapes dominated weeds. The weed infestation are light, so , this cultrual practice was adopted as the tradional weed control method.

2, Herbicide evaluation

Direct-seeded rape crop: The Traflan 750g/ha, Deverinol 740g/ha and Stomp 740g/ha were applied in pre- emerge. The Traflan controls *Alopecurus aequalis, Poa annual* and *Malachium aquaticum* with an efficacy of 92. 7%, 93. 6% and 89% respectively. The Deverinol controls above metioned with an efficacy of 86. 1%, 93 . 4% and 82. 2% respectively. The Stomp controls at 74. 3%, 79. % and 98. 6%. The data showed that the Traflan and Deverinol control grass weeds *Alopecurus aequalis* and *Poa annual* better than broad-leafed weeds like Malachium aquaticum. But Stomp is adverse.

The *Alopecurus aequalis, Poa annual* and some of *Malachium aquaticu* were controlled by Acetchlor in early post-emerge, with wide spectrum weed control. But Sethoxydin and Galtak only control one kinde of weed, such as The Sethoxydin can control *Alopecurus aequalis*, not control *Malachium aquaticum* and *Poa annual*, The Galtak can control *Malachium aquaticum*, not control grass weed, It showed that Deverinol, Stomp and Traflan gave good weed control and was safty to the crop, increasing yield evidently (table 1, 2)

Table 1 Effects of herbicides on weed population and weed control efficacy in tilled direct-seeded rape field

Treatment (ml/mu)	*Malachium aquatica/um* Efficacy(%)	*Alopecurus aequalis* Efficacy(%)	*Poa annual* Efficacy(%)	*Total weed* Efficacy(%)
Stomp 740g/ha (Pre-emergenee)	98.2	74.3	79.0	90.3
Stomp 740g/ha (Post-emergence)	99.4	33.3	0	71.8
Acetochlor 562g/ha (Post-emergence)	63.9	99.8	75.8	74.1
Devrinol 740g/ha (Pre-emergence)	82.2	86.1	93.4	84.4
Trifluralin 750g/ha (Pre-emergence)	89.0	92.7	93.6	90.4
Poast 120g/ha (Pre-emergence)	0	99.5	0	3.1
Galtak 300g/ha (Pre-emergence)	99.7	0	0	47.1
CK/0.11m²	394.0g	151.3(g)	62.4(g)	607.6(g)

Till transplanted rape: Acetchlor 562g/ha and Chlortoluron 1125g/ha applied pre-plant to control *Alopecurus aequalis malachium aquaticum* and *Poa annual* with an efficacy of 99.1%, 89.6%; 87.2, 97.6%, and 96.8%, 87.2% respectively (table 3, 4).

Table 2 Effect of different herbicides on rape yield in tilled direct-seeded rape field

Treatment (ml/mu)	Pod number /plant	Grains /pod	1000-grain weight(g)	Yield/ha (kg)	Increase rate (%)
Stomp 740g/ha (Pre-emergence)	200	11.2	3.51	2556	52.5
Stomp 740g/ha (Post-emergence)	142	8.8	4.0	1623	-2.2
Acetochlor 562g/ha (Post-emergence)	148	9.35	4.5	2038	21.7
Devrinol 750g/ha (Pre-emergeme)	195	9.27	4.08	2397	43.0
Trifouralin 750g/ha (Pre-emergence)	176	9.1	4.18	2175	29.8
Poast 120g/ha (Post-emergence)	157	11.1	3.92	2220	32.5
Galtak 300g/ha (Post-emergence)	150	8.93	4.27	1858	10.9
CK	151	8.17	4.18	1677	-

Table 3 Effect of herbicides on weed species community and control in tilled transplanting rape field

Treatment (ml/mu)	*Malachium aquaticum* Efficacy(%)	*Alopecurus aequalis* Efficacy(%)	*Poa annual* Efficacy(%)	Total weed controly Efficacy(%)
Chlortoluron 1125g/ha (Before transplanting)	96.8	97.6	87.2	96.4
Acetochlor 562g/ha (Before transplanting)	89.6	99.1	87.2	93.0
Poast 120g/ha (After transplanting)	0	99.7	0	16.6
Galtak 300g/ha (After transplantingg)	94.5	0	0	43.2
CK/0.11m^2	351.8g	236.0g	44.6g	632.4g

Table 4 Effect of different herbicides on rape yield in tilled transplanting rape field

Treatment (ml/mu)	Pod number /Plant	Grains /pod	1000-grain weight(g)	Yield/ha (kg)	Increase rate (%)
Chlortoluron 1125g/ha (Before transplanting)	404	18.4	3.70	1971 c	74.3
Poast 120g/ha (Beford transplanting)	309	14.3	3.08	1203 ab	6.4
Acetochlor 562g/ha (Before transplanting)	413	17.9	3.80	2148 c	78.0
Galtak 300g/ha (After transplanting)	263	17.3	3.60	1174 a	3.8
CK	270	16.7	3.50	1131 a	-

The datas showed that Deverinol, Stomp can be used in direct-seeded in pre- emerge rape fields. The Acetchlor and Chlortoluron can be used in transplanted rape field. The Sethoxydin and Galtak only can be used in grass or broad leafed weeds single population fields.

REFERENCES

1, Tang H. 1987.
Weed chemical control in field.

2, Tang H. Y. 1982.
Study of weed control strategy in field
Information of agriculture in China.

3, Black. J.N. 1958.
Competition between plants of different initial seed size in swards of subterranean clover with particular reference to light microclimate. Australia J. Agri. Res., 9, 299-318.

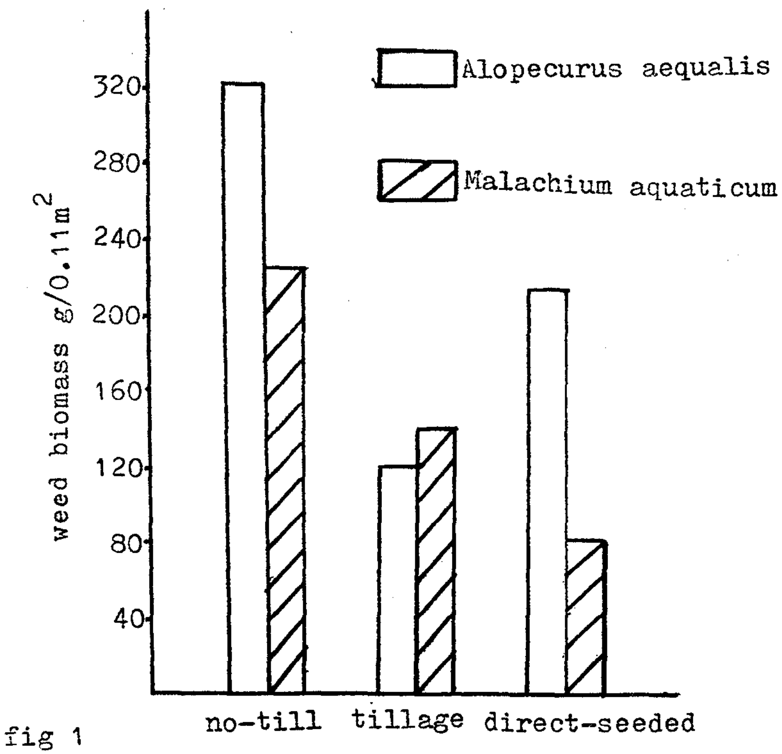


fig 1

Comparision weed biomass in rape field
under different cultural practice

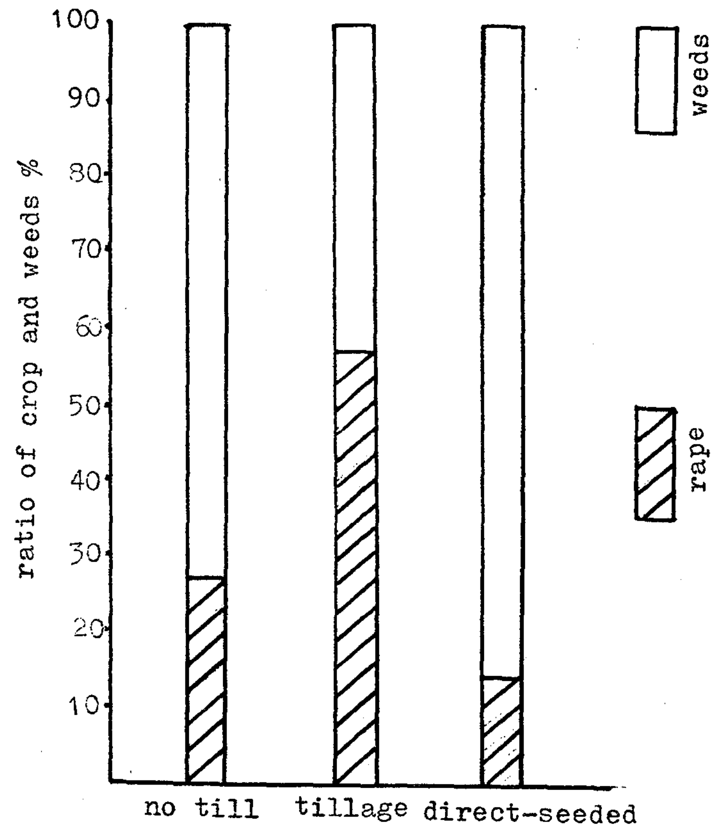


fig 2 The ratio of crop and weeds in rape
under different cultural pratice

Architecture and Responses to Foliar-applied Herbicides of the *Equisetum arvense* (Field Horsetail) Subterranean System

M. Ito and M. Asai
Faculty of Agriculture, Kyoto University, Sakyoku, Kyoto 606, Japan

Abstract.. *Equisetum arvense* L. (field horsetail), a perennial cosmopolitan, is widely distributed as a noxious agricultural weed in Japan. Established plants are tolerant to all means of control, because of their extensive subterranean system consisting of rhizomes and tubers. Studies were conducted on this subterranean system to investigate 1) its distribution in the soil profile and 2) its responses to foliar-applied herbicides. Most subterranean parts were located 30-50 cm deep in a corn field, but were at 10-20 cm in a neighboring noncultivated area, although the amount was considerably larger in the latter. Asulam, glyphosate, glufosinate and triclopyr were repeatedly applied in September and the following June to established stands of *E. arvense*. Spring shoot growth after the first application was not reduced in the treated plots except for a slight reduction in the asulam treatment. With the second application of these herbicides, however, regrowth was suppressed for more than 10 months, and in both glyphosate and asulam treated plots few shoots emerged in the following spring. The amount of living rhizomes harvested 3 months after the second application was smaller only in the upper 10 cm in all treatments. No decrease was observed in tubers. Sprouting ability of rhizomes treated with asulam, triclopyr and glyphosate was reduced to lower than 40 % of the control even in those harvested from 20-30 cm deep, exhibiting the translocation of the herbicides to this depth. Significant inhibition of sprouting occurred down to 20 cm in glyphosate and triclopyr treated tubers. Some of the asulam or glyphosate treated rhizomes and tubers exhibited abnormal sprouting, repeating sprouting and termination of growth.

Keywords: Equisetum arvense, asulam, glyphosate, perennial weed control, rhizome system.

Introduction

Creeping perennials develop extensive subterranean architecture, and their established stands are very difficult to control by ordinary methods. The difficulty lies not only in the characteristics of these species but also in that their underground behavior has been little known. *Equisetum arvense* L. has a particularly well developed and aggressive rhizome system, the study of which may provide us with valuable information for the control of this type of weed.

E. arvense is a cosmopolitan widely distributed in the temperate regions as a noxious agricultural weed in more than 25 crops. It causes growth inhibition and yield loss of crops. The weed has also been shown to be poisonous to the animals when mixed in forage plants and fed, because of the presence of a thiamine-destroying substance. Underground parts of its established stands, known to extend to 1 to 2 m depth (4, 10), consist of vertical rhizomes supporting aerial shoots at the top, horizontal rhizomes from which the verticals derive, and tubers attached to some rhizome nodes. Furthermore, rhizome segments and tubers act as vegetative propagules and are able to sprout at any time of the year if conditions are favorable. Therefore, either intensive tillage or soil applied residual herbicides are not thought to provide sufficient control of this species, and the use of translocated foliar-applied herbicides may be a more promising method to attack its underground parts. The objectives of these experiments were to determine the distribution of the *E. arvense* subterranean system in the soil profile and its responses to foliar-applied herbicides.

Materials and methods

1. Distribution in the soil profile. Field research was conducted at the Experimental Farm of Field Crop Branch of Hokkaido National Agricultural Experiment Station (soil: volcanic ash) at Memuro, Tokachi. In mid-September, when *E. arvense* had fully grown, three 50 × 50 cm quadrats were randomly placed in the stands in a corn field and a neighboring noncultivated area. Subterranean parts were harvested from each plot within 10 cm layers from 0 to 60 cm deep. Harvested rhizomes, tubers, thick roots and overwintering buds were separated and weighed, and vertical rhizome emergence in each depth zone was recorded.

2. Responses to foliar-applied herbicides. The experiment was conducted using established *E. arvense* stands along the edge of an orchard at the Experimental Farm, Kyoto University in Osaka. Two 2 × 4 m plots were used for each treatment. Glyphosate as isopropylamine salt at 7.18 kg ae/ha, asulam as sodium salt at 8.05 ai/ha, glufosinate as ammonium salt at 1.88 ae/ha and triclopyr as triethylammonium salt at 4.58 kg ae/ha were repeatedly applied on September 24, 1993 and June 1, 1994. Herbicides were diluted to 1,000 *l*/ha with tap water and sprayed over the canopy of the shoots by a battery-powered 2 *l* portable sprayer. Percent ground cover by *E. arvense* shoots in the plots at the time of the first application was 75 to 90 %. Change in percent ground cover by its living shoots was visually estimated. During September 3 to 6, 1994 the subterranean parts were harvested to determine the effects of the herbicides on these parts. Soils in two 50 × 50 cm quadrats near the center of each plot were dug out to 30 cm depth for every 10 cm. All plant parts were collected, living and dead rhizomes and tubers were separated, and weighed. Fifty 1-node segments of the rhizomes and 50 single tubers from each soil sample were then tested for sprouting ability under 20 °C in darkness for 14 days.

Results

1. Distribution in the soil profile. Distribution of the subterranean system in the soil profile was deeper in the corn field than in the noncultivated area, although the total amount was much larger in the latter (Table 1). The zone of maximum distribution was 40 to 50 cm in the corn field stands suggesting the presence of rhizomes considerably below 60 cm, while it was 10 to 20 cm in the noncultivated stands. It is worth noting that in the corn field the amount of live rhizomes was small above 30 cm depth. This was probably because the field had been cultivated to 30 cm once or twice a year. Another difference between the two fields was that thick roots were found deeper in the noncultivated area (Table 1).

Besides these essential organs, overwintering buds were also found in this survey, just below the soil surface (0~10 cm in Table 1), which develop during the autumn These buds support thick new vegetative shoot growth at the beginning of the growing season in spring. Thereafter, the plants continue to produce new shoots throughout the season from the small lateral buds at rhizome nodes via vertical rhizomes but not from the large overwintering buds. Most of the vertical rhizomes extended above 30 cm depth in the corn field and above 20 cm depth in the noncultivated area.

Table 1. Fresh weight of subterranean organs* and number of vertical rhizome emergence* at difference depths in a corn field and a noncultivated area.

Stand	Depth zone (cm)	RHI	TUB	TRT	OWB	Total	Vertical rhizome number(/m^2)
		Fresh weight (g/m^2)**					
Corn field	Aerial shoot					245.3	
	0~10	17.3	4.5	0.0	1.5	23.3	40
	10~20	15.1	4.1	0.0	0.4	19.6	25
	20~30	21.6	7.4	0.0	0.0	29.0	28
	30~40	26.1	46.7	0.1	0.0	72.9	13
	40~50	20.9	61.7	0.0	0.0	82.6	8
	50~60	12.7	31.5	0.0	0.0	44.2	0
Noncultivated area	Aerial shoot					770.7	
	0~10	25.3	170.3	0.5	73.2	269.3	476
	10~20	521.6	234.7	4.7	1.3	762.3	404
	20~30	197.9	135.3	4.8	0.7	338.7	52
	30~40	96.7	53.7	9.7	0	160.1	16
	40~50	23.6	16.9	18.1	0	58.6	4

* Means of 3 replicates.

** Abbreviations: RHI=Rhizome, TUB=Tuber, TRT=Thick root, OWB=Overwintering bud.

2. Responses to foliar-applied herbicides. In the first application none of these herbicides provided efficient reduction of shoot regrowth in the following spring (Table 2). After the second application, however, shoot emergence was greatly reduced, even in the following April, 10 months after the application. In particular, few shoots were found in the glyphosate and asulam treatments, although complete death of herbicide sprayed shoots occur very slowly for glyphosate and asulam compared to the other 2 herbicides.

Table 2. Changes in visual estimate of living *E. arvense* ground cover, affected by different herbicide application.

Herbicide		Cover estimated (%)				
	Date	9/12/93	11/9/93	5/18/94	8/11/94	4/21/95
	DAT, 1st*	-12	46	236		
	DAT, 2nd*			-14	71	324
Asulam		90.0	10.0	57.5	0.0	1.5
Glufosinate		85.0	10.0	100.0	5.0	27.5
Glyphosate		87.5	25.0	95.0	2.5	1.5
Triclopyr		77.5	0.0	87.5	0.0	12.0
Untreated		82.5	95.0	95.0	37.5	42.5

* Days after the first and the second application.

The quantity of rhizomes decreased a little and that of tubers did not decrease after the repeated herbicide application, except for a relative decrease in triclopyr plots (Table 3). The decrease mainly appeared in the upper 10 cm zone (data is not shown). However, sprouting from the living rhizomes and tubers were remarkably inhibited (Table 4). High inhibitory effect was obtained for the glyphosate treatment, even on rhizomes harvested from 20 to 30 cm deep, but for the other 3 herbicides the inhibition, although significant, became weaker in the deeper rhizomes and tubers. Most unsprouted rhizomes and tubers did not produce any sprouts, while some from the plants treated with asulam or glyphosate failed to produce normal shoots due to repeated sprouting and death of growing points.

Table 3. Fresh weight of rhizomes and tubers harvested from 0~30 cm depth, 3 months after the second herbicide application*.

Herbicide	Living part (g/m^2)**			Dead part (g/m^2)**		
	Rhizome	Tuber	Total	Rhizome	Tuber	Total
Asulam	253.8b	97.6b	351.4ab	80.9b	1.05ab	82.0b
Glufosinate	217.4c	81.0b	298.4b	79.4b	1.66a	81.1b
Glyphosate	331.8ab	187.7a	519.5a	70.5b	0.65b	71.1b
Triclopyr	207.1c	137.5ab	344.6b	125.5a	0.65b	126.2a
Untreated	368.7a	86.4b	455.1ab	69.4b	0.98ab	70.4b

* September 3 to 6, 1994.

** Means over 4 guadrates from 2 plots. Values within a column followed by the same letter are not significantly different at the 5% level according to LSD by ANOVA.

Table 4. Percent sprouting of rhizomes* and tubers** harvested from 0~30 cm depth, 3 months after the second herbicide application.

Herbicide	Rhizomes sprouted(%)*** Depth zone(cm)			Tubers sprouted(%)*** Depth zone(cm)		
	0~10	10~20	20~30	0~10	10~20	20~30
Asulam	5.0c	12.5d	34.0c	15.4ab	21.5ab	38.5a
Glufosinate	27.7ab	45.2b	66.5b	29.7ab	41.5a	34.0a
Glyphosate	16.5bc	26.0c	15.5c	9.5b	3.5b	6.5b
Triclopyr	7.5c	13.0d	34.0c	11.3b	13.0b	32.5a
Untreated	59.0a	82.5a	86.5a	38.9a	52.0a	52.5a

* 3 cm segments with 1 node, ** Single tubers detached from rhizomes.

*** Means within a column followed by the same letter are not significantly different at the 5% level according to LSD for the arcsine-transformed values.

Discussion

A number of creeping perennials rhizomatous species such as *E. arvense*, *Artemisia princeps* (Japanese mugwort), *Kalimeris yomena*, *Calystegia* spp. (Japanese bindweed). *Imperata cylindrica* (cogongrass), *Agropyron repens* (quackgrass), *Sorghum halepense* Johnsongrass), *Cyperus rotundus* (purple nutsedge, reproducing by tubers), and the species having creeping roots as *Convolvulus arvensis* (field bindweed), *Cirsium arvense*, (Canada thistle), *Rumex acetosella* (red sorrel) are regarded as noxious weeds in crop fields. Among these species *E. arvense* as well as *Calystegia* spp. develops rhizome systems most extensively and aggressively. In such kind of species, it seems to be difficult to kill the whole underground system. A more promising means, therefore, is to suppress shoot emergence as long as possible, causing the exhausting of food reserves and subsequent death. As aerial shoots emerge from rhizome buds, the critical factor for controlling these weeds is to kill buds or inhibit bud sprouting to the necessary depth with symplastically translocated foliar-applied herbicides. Few studies (1, 5, 8, 9), however, were reported on the herbicidal effects on rhizome buds.

Our study proved that glyphosate and asulam at high rates are able to suppress regrowth of *E. arvense* almost completely for a long period. Other evidence suggests that glyphosate at 4 kg/ha and asulam at 8 kg/ha significantly reduced shoot regrowth (2). Table 1 shows that most of the aerial shoots were found to come from the upper 30 cm in the cultivated field and the upper 20 cm in the noncultivated area, and Table 4 indicates that the herbicides could translocate to rhizomes as deep as 30 cm, enough depth for control. Glyphosate seems particularly mobile (Table 4). In the study on *Agropyron repens* glyphosate was not distributed evenly in rhizomes, and accumulated more in the apical portions than the base of the treated shoot (1). In our study some of the rhizome segments and tubers collected from asulam or glyphosate treated plants failed to produce normal shoots by repeating sprouting and the death of the apical portions. Asulam is also known to accumulate strongly in rhizome buds in *Pteridium aquilinum* (bracken fern) (10). All these facts suggest high sink-dependence in the translocation of both herbicides. Effect on the reduction of new shoot emergence in the following season was higher for the asulam treatment than the triclopyr treatment, although the effects on rhizomes and tubers did not differ for the two herbicides. This may be attributed to long life of asulam in the plants, for 8 % of applied activity of ^{14}C-asulam was reported to remain in rhizomes in *P. aquilinum* even 40 weeks after application (1).

In the experiment for *E. arvense* control, the second application practiced in early June was more effective for all herbicides than the first application in late September, because the effects of the first application seemed negligible at the time of the second application. Symplastically translocated herbicides tend to move to the points of active growth and/or food storage accumulation, and so efficacy on perennials is generally greater at maturity (usually autumn) of plants when downward movement of photosynthates becomes active. However, in *E. arvense* the maximum food accumulation in subterranean organs appeared during June to July, much earlier than in other species, when aerial growth was most active (7). Therefore, it is not surprising that the June application was more effective than the September application in this study. Further studies would be required to know the most effective application timing and the precise depth to which the effects reach.

Acknowledgments

The authors express their appreciation to M. Ikeda, J. Kodo, H. Oka. T. Tetsumura and H. Kawahara for their technical assistance and advice, and J. L. Breen for his comment on the manuscript. We also wish to thank the Ministry of Agriculture, Forestry and Fisheries and Monsanto Japan for financial support of these studies in part.

References

1. Claus, J. S. and R. Behrens. 1976. Glyphosate translocation and quackgrass rhizome bud kill. Weed Sci. 24: 149-152.
2. Coupland, D. and D. V. Peabody. 1981. Effect of four foliage-applied herbicides in field horsetail (*Equisetum arvense*). Weed Sci. 29: 113-119.
3. Devine, M. D. 1989. Phloem translocation of herbicides. Rev. Weed Sci. 4: 191-214.
4. Holm, L. G., D. L. Plucknett, J. V. Pancho and J. P. Herberger. 1977. The World's Worst Weeds.
5. Ito, M., K. Ueki, M. Ikeda, J. Kudo, and H. Oka. 1985. Distribution pattern and effects of tillage and asulam on *Equisetum arvense*. Weed Res., Jap. 30 (suppl.) : 171-172 (In Japanese).
6. Ito, M. 1992. Biology of perennial weeds: as a basis for their control. Korean J. Weed Sci. 12: 309-316.
7. Ito, M. and Y. Watanabe. 1994. Phenology of field horsetail (*Equisetum arvense* L.) a noxious perennial weed in field crops. Bull. Exp. Farm Kyoto Univ. 4: 9-16 (In Japanese with English summary).
8. Motegi, H. and M. Ito. 1995. Effect of foliar-applied herbicides on *Convolvulus arvensis* and *Calystegia hederacea* in different growth stages. Weed Res., Jap. 40 (suppl.): 130-131. (In Japanese).
9. Stoltenberg, D. E. and D. L. Wyse. 1986. Regrowth of quackgrass (*Agropyron repens*) following postemergence applications of haloxyfop and setoxydim. Weed Sci. 34: 664-668.

10. Veerasekaran, P., R. C. Kirkwood and W. W. Fletcher. 1977. Studies on the mode of action in bracken (*Pteridium aquilinum* L. Kuhn) I. Absorption and translocation of ^{14}C asulam. Weed Res. 17: 33-39.
11. Williams, E. D. 1979. Studies on the distribution and growth of *Equisetum arvense* L. (field horsetail) from tubers Weed Res. 19: 25-32.

Adapted Weed Management: Long-term Effects on Weed Flora, Maize Yield and Profitability

K. F. Kon[1], K. P. Tiw[1] and J. L. Allard[2]
[1] Ciba Research Station, Locked Bag, 71309 Rembau, Negri Sembilan, Malaysia
[2] Ciba-Geigy Ltd., PP 6.25, Postfach CH-4002 Basel, Switzerland

Abstract. In a long-term field study and subsequent on-farm trials, we integrated low rates of herbicides with manual weeding and tillage to sustain crop production and minimize impact on the environment. The long-term study was carried out on maize, soybean and upland rice in different cropping systems on a typical Ultisol on-station. After six seasons, annual grasses increased in full tillage whereas annual dicots dominated in zero tillage. In full tillage, appropriate management of weeds was possible with: 1) intensive multiple hoeings; 2) full rates of herbicides without hoeing; and 3) reduced herbicide inputs with light to moderate hoeing. These techniques were also effective in managing weeds in zero tillage, but a suitable pre-plant non-selective herbicide was necessary. We extended to sweet corn in farmers' fields the techniques of low rates of herbicides with hoeing in full tillage and full herbicides without hoeing in zero tillage. These techniques achieved up to 70% extra weed control relative to farmers' practices. In all cases, the techniques were more profitable. With the results obtained on-station, we derived a decision tree to decide the broad weed management techniques that would overall fit the different weed situations, technical skills and available resources of the farmers.

Key Words. Adapted weed management, maize, tillage, low-rates of herbicides, Southeast Asia.

Introduction

In Southeast Asia, both paddy and upland farmers will need to increase food production to feed the growing population (Beets 1990). Upland farmers face severe weed competition and control weeds with intensive tillage and hoeing. On sloping and marginal land, tillage and hoeing reduce production even further through soil erosion and degradation. The loss of soil fertility reduces yield rapidly, prevents profitable farming, and encourages shifting cultivation and poverty.

Adapted weed management techniques in the tropics (AWMTT) aims to establish that profitable upland farming is possible with the use of low rates of herbicides to complement manual weeding (Ebner 1982; Zoschke *et al.* 1990; Kon *et al.* 1992; Kon 1993; Tiw *et al.* 1994; Zoschke 1994). However, the derived weed management techniques must be simple, flexible and adaptable to varying situations. Also, the techniques should be sustainable under the humid, tropical environment. This paper presents the maize results of a long-term study on-station and the adaptation of two broad techniques on-farm in Malaysia. We enlarge on the partial results published elsewhere (Tiw *et al.* 1994).

Materials and Methods

Long-term Study at Ciba Research Station

A field trial was conducted at Ciba Research Station, Rembau on a low-fertility Ultisol (Rengam series), which is the largest representative soil group in Southeast Asia (FAO 1988). At the beginning of the trial, the soil contained 1.6% organic carbon, 0.18% nitrogen, 13 ppm available phosphorus, 27 ppm potassium, 230 ppm calcium, 34 ppm magnesium, 347 ppm iron, 60% aluminium saturation and 28% base saturation in the first 15 cm depth. The soil pH was 4.8 in both the first and next 15 cm horizons.

The trial was a split-block design with four replications. The main blocks were combinations of full and zero tillage with either a cereal or legume, and a zero tillage combined with alley cropping (*Gliricidia sepium* (Jacq.) Kunth ex Walp.). The alley crop was in double rows of 0.5 m apart with 4 m between alleys. The cropping sequence was maize (Ciba G5440), maize (Ciba G5431), soybean (cv. Palmetto), maize (Ciba G5440), upland rice (cv. IR53236-275-1) and soybean (cv. Palmetto) over the full three years from August 1991 to July 1994. The sub-plots were five weed management techniques: untreated check, manual weeding by hoeing, full rates of pre- followed by post-emergence herbicides, low-rates of pre- followed by post-emergence herbicides with one hoeing, and low rate of a post-emergence herbicide with one hoeing. Each plot was 10 x 10 m^2.

Full tillage involved one disk ploughing and either two diskings and/or rotovations to control weeds after fallow. In zero tillage, fallow weeds were controlled by glyphosate (Roundup 36% ae) at 720 g ae/ha and 2,4-D BE (Rumputox 45% ae) at 720 g ae/ha at 14 days before sowing (DBS). Pre-emergence herbicides were applied at 0-5 days after sowing (DAS) and post-emergence herbicides at 2-4 leaf stage of the weeds (Table 1). Hoeing was around 15-20 DAS and 30-35 DAS. The aim of weed management was to keep weeds at about 20% soil cover up to 50 DAS irrespective of the technique (Ebner 1982).

Table 1. Pre-emergence (PRE) and post-emergence (POST) herbicides used in the weed management techniques.

Crop	Herbicide input level	PRE herbicides (g ai/ha)	POST herbicides (g ai/ha)
Maize		**Atrazine+ metolachlor (Gesaprim 50%+Dual 72% ai)**	**Terbuthylazine (Gardoprim 50% ai)**
	None (check)	0	0
	None (2x manual)	0	0
	Low POST[1]	0	500
	Low PRE & POST[1]	500+500	500
	Full PRE & POST	1000+1000	1000
Soybean		**Metolachlor**	**Fomesafen (Flex 25% ai)**
	None (check)	0	0
	None (2x manual)	0	0
	Low POST[1]	0	250
	Low PRE & POST[1]	500	250
	Full PRE & POST	1000	500
Upland rice		**Oxadiazon (Ronstar 12% ai)**	**Clodinafop+prosulfuron**
	None (check)	0	0
	None (2x manual)	0	0
	Low POST[1]	0	15+10
	Low PRE & POST[1]	300	15+10
	High PRE & POST	600	30+20

[1] With one supplementary hoeing.

Each season, a basal NPK equivalent to 25 kg N/ha, 25 kg P_2O_5/ha, 35.4 K_2O/ha and 5.2 kg MgO/ha was applied just after sowing. At about 30 DAS, additional N at 25 kg/ha was applied as urea in the maize and rice crop only. In the first three and the fifth crops, lime was applied at 2 t/ha at about 22 DBS to maintain the soil pH to 6-6.5. We applied insecticides and fungicides when necessary.

Adaptation of Techniques in Sweet Corn Areas, Rembau

After three seasons of maize, we proceeded with on-farm testing on sweet corn (local open-pollinated *Mas Madu*) around Rembau. The design was a series of single-replicate, large-plot trials, repeated over farms and seasons (Jonestone and Lowther 1993) from April to December 1993 (Table 2). On each farm, the farmer's practice was compared with the two most promising techniques from the long-term study. These promising techniques were full tillage with low rates of pre- followed by post-emergence herbicides and zero tillage with full rates of pre- followed by post-emergence herbicides. The latter technique was included because tractor was not readily available and expensive to hire (RM 130/ha for each cultivation). The low-rate techniques included one hoeing to keep weeds at about 20% soil cover up to 50 DAS. Plot size ranged from 200 to 960 m^2 depending on farm size.

On all farms, the soil is a riverine alluvium that supported transplanted rice about 10 years ago. The soil samples from all farms averaged 1.04% organic carbon, 0.17% nitrogen, 50 ppm available phosphorus, 89 ppm potassium, 511 ppm calcium, 81 ppm magnesium, 145 ppm iron, 32% aluminium saturation and 43% base saturation in the first 15 cm depth. The soil pH was 5.3 in the first 15 cm and 4.8 in the next 15-30 cm horizons. All treatments in each trial received the same fertilizers, and pest and disease management according to the farmer's practice.

Table 2. Comparison of weed management techniques in the on-farm trials.

Season	Farm[1]	Farmer's practice		Full tillage Low PRE and POST[2]		Zero tillage Full PRE and POST[3]	
		Tillage (no.)	Herbicides (g ai/ha)	Tillage (no.)	Herbicides (g ai/ha)	Tillage (no.)	Herbicides (g ai/ha)
1	A	2	600	2	1'300	0	4'100
	B	2	1'040	2	1'600	0	2'900
	C	3	0	2	1'200	0	4'900
2	A	1	720	1	1'140	0	3'540
	B	2	770	2	1'080	0	3'040
	C	2	0	1	1'000	0	3'900
	D	2	0	1	1'450	0	3'440
Range		1-3	0-1'040	1-2	1'000-1'600	0	2'900-4'900
Mean ± SE[1]		2.0 ± 0.2	447 ± 166	1.6 ± 0.2	1'253 ± 80	0	3'689 ± 259
Proportion (%)		100	100	80	280	0	825

[1] A, Chengkau E; B, Chengkau 2; C, Sawah Raja; D, Pelangai Hilir. SE=standard error of mean.
[2] Atrazine, metolachlor with glufosinate (Basta 15% ae) depending on time after land preparation.
[3] Atrazine and metolachlor; glufosinate or glyphosate+2,4-D BE at pre-planting depending on weeds.

Results and Discussion

Long-term Study at Ciba Research Station

Increasing level of herbicides increased the level of effective weed management in full and zero tillage (Table 3). Tillage with herbicides kept weeds below 11%. Herbicides without tillage maintained weeds at about 5-20%; pruning from the alley crop (*Gliricidia sepium*) reduced weeds further by 3-5% probably through allelopathy (Kon *et al.* 1992). However, pruning required additional labour of 17-20 man-days/ha. In both full and zero tillage, herbicides reduced weeding labour from 63-85 man-days/ha to less than 44 man-days/ha (Table 3).

Table 3. Comparison of weed management techniques in maize over three seasons at Ciba Research Station, Rembau.

Tillage	Weed management technique	Weed cover±SE[1] (%)	Weeding labour±SE[2] (man-day/ha)	Maize yield±SE (t/ha)	Return to weeding[2] (RM/ha)
Full tillage/ maize	Untreated check	71 ± 10.7	2 ± 0.3	3.5 ± 0.25	0
	Manual weeding	19 ± 1.8	85 ± 5.7	5.3 ± 0.16	-471
	Full PRE & POST	3 ± 0.6	4 ± 0.3	5.4 ± 0.22	**417**
	Low PRE & POST	5 ± 0.9	15 ± 5.5	5.3 ± 0.25	**311**
	Low POST	11 ± 1.8	36 ± 7.2	5.2 ± 0.13	**75**
Zero tillage/ maize	Untreated check	88 ± 5.7	3 ± 1.2	2.3 ± 0.22	0
	Manual weeding	26 ± 4.5	93 ± 10.0	3.2 ± 0.27	-800
	Full PRE & POST	11 ± 2.1	5 ± 1.2	3.7 ± 0.21	**273**
	Low PRE & POST	14 ± 3.1	30 ± 5.2	3.6 ± 0.27	**18**
	Low POST	19 ± 3.7	44 ± 3.8	3.1 ± 0.29	-258
Zero tillage/ maize with alley crop	Untreated check	81 ± 4.5	3 ± 1.2	2.4 ± 0.36	0
	Manual weeding	19 ± 2.6	63 ± 5.0	2.9 ± 0.24	-585
	Full PRE & POST	6 ± 1.4	4 ± 1.5	3.4 ± 0.27	**169**
	Low PRE & POST	11 ± 1.7	24 ± 5.6	3.6 ± 0.29	**29**
	Low POST	15 ± 2.6	32 ± 6.9	3.1 ± 0.30	-179

[1] Visual assessment at 50 DAS; SE, standard error of mean.
[2] Weeding labour = tillage + herbicide application + hoeing; return to weeding = sales of maize yield (treatment-check) - weeding costs (treatment-check); RM 1.00 = US$ 0.40.

Maize produced similar yield in all weeded treatments either with manual hoeing or herbicides in full tillage (Table 3). In zero tillage, however, treatments with inputs of above 50% pre-emergence and post-emergence herbicides yielded more than the other treatments. Maize yield was higher in full than in zero tillage because tillage mixed the lime into a depth of 30 cm in the soil and, thus, reducing toxic levels of aluminium in the lower soil profile (Tiw *et al.* 1994). Across the three seasons, maize yield was stable despite the low inputs of fertilization. In terms of return to weeding, increasing levels of herbicides increased the profitability of the weed management techniques in both full and zero tillage (Table 3). However, there was no advantage of alley cropping in zero tillage over the maize mono-cropping in zero tillage.

Over six seasons of cropping, two major trends on weed flora were evident. Firstly, full tillage encouraged the proliferation of annual grasses such as *Eleusine indica* (L.) Gaertn. and *Digitaria ciliaris* (Retz.) Koel. (Figure 1a, 1b and 1d). However, zero tillage maintained high level of annual dicots including *Borreria latifolia* (Aubl.) K. Schum., *Asystasia gangetica* (L.) T. Anders., *Euphorbia heterophylla* L. and *Ageratum conyzoides* L. although grasses also increased (Figure 1a, 1b and 1d). Secondly, pre-emergence herbicides were necessary to manage grasses after two to three cropping seasons (Figure 1c and 1d). The weed flora developed similarly in both the full and low rates of herbicides irrespective of tillage (Figure 1c). Manual weeding was less effective on grasses than on dicots because the growing points of grasses at soil level survived better after hoeing. The low rate of terbythylazine followed by hoeing was superior to hoeing (2x) in managing the weeds. The perennial, *Brachiaria* sp., built up during fallows but tillage or the pre-plant herbicides controlled this grass well.

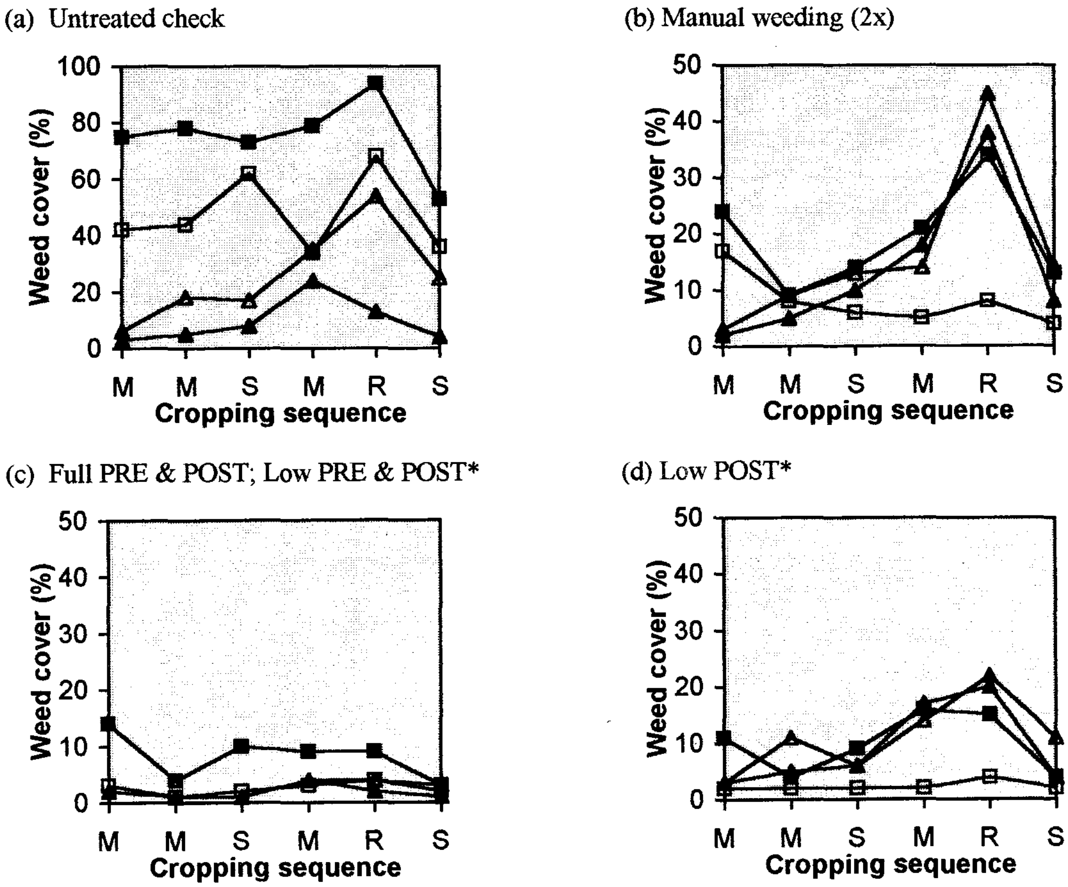


Figure 1. Effect of weed management techniques on the weed flora over six seasons at Ciba Research Station, Rembau. Weed cover by visual assessment at 50 DAS. Crop sequence was M=maize; S= soybean; and R=upland rice. *There was one hoeing in low PRE & POST and low POST treatments. Grasses (circles); dicots (squares); full tillage (open); and zero tillage (filled).

Adaptation of Techniques in Sweet Corn Areas, Rembau

Farmers' practices were very heterogeneous as expected (Table 2). Farmers in farm A and B already were using some herbicides, while farmers in farm C and D practiced only tillage and hoeing. In farm A and B, where herbicides were used, farmers achieved substantial savings in weeding labour (Table 4) and weeding costs. Without herbicides, however, the workload required for weeding was high, ranging from 33-45 man-days/ha. On the average, weeding labour decreased by 62-82% and 15-39% with the adapted techniques. Zero tillage used more labour than full tillage because of higher weed pressure in zero tillage.

Both techniques managed the weeds to about 7-15% except in farm A, B and C in the second season when tillage or glufosinate did not controlled completely the weeds prior to sowing (Table 4). As a result, weed cover in the second season was higher than in the first season with the usual annuals mixed with some *Cyanodon dactylon* (L.) Pers. For the techniques to be sustainable, there must be proper tillage or application of an effective pre-plant herbicide. Nevertheless, weed management was superior to farmers' practices (bold data in Table 4). Also in all cases, the adapted weed management techniques in full and zero tillage, respectively, produced 159% and 206% higher profits than farmers' practices (US$ 483/ha). Yield obtained under zero tillage was superior to the yield under full tillage because the more fertile alluvial soil supported zero tillage better than the poorer Ultisol on-station.

Table 4. Effects of adapted weed management on workload and weed cover on-farm at Rembau.

Season	Farm[1]	Weeding labour (man-day/ha)[2]			Weed cover (%)[3]		
		Farmer's practice	Full tillage Low PRE & POST	Zero tillage High PRE & POST	Farmer's practice	Full tillage Low PRE & POST	Zero tillage High PRE & POST
1	A	6	6	10	25	**12**	**12**
	B	1	3	6	53	**7**	**9**
	C	36	**4**	**7**	53	**15**	**11**
2	A	1	2	5	100	**36**	**24**
	B	2	2	9	99	**35**	**38**
	C	45	**4**	**5**	100	**35**	**37**
	D	33	**1**	**5**	32	**10**	**9**
Range		1-45	1-6	5-10	25-100	7-36	9-38
Mean ± SE[1]		18 ± 7.3	3 ± 0.6	7 ± 0.8	66 ± 13	21 ± 5	20 ± 5
Proportion (%)		100	18	38	100	32	30

[1] A, Chengkau E; B, Chengkau 2; C, Sawah Raja; D, Pelangai Hilir. SE=standard error of mean.
[2] One man-day = 8 hours.
[3] Visual assessment at 50 DAS.

Conclusions

The broad techniques of weed management, integrating low rates of herbicides with manual weeding, were promising in the long-term study at Ciba Research Station. This replicated study on a single, relatively homogenous site produced precise results with low variability. Such results obtained on-station provided an excellent basis to derive a decision tree to decide the broad weed management techniques that would overall fit the different weed situations, technical skills and available resources of the farmers (Figure 2). However, there will be still a need to check and adapt the selected techniques to local conditions. The selected techniques may also evolve with time according to farmers' needs

Extending on-farm with the active ingredients and rates applied, these techniques managed weeds to an average of 20% on a more fertile alluvium. The adapted techniques increased sweet corn yield and maintained high profits in all farms over two seasons. Zero tillage was also superior to farmers' practices, provided full rates of herbicides including suitable pre-plant herbicides such as glyphosate and 2,4-D BE were used. As tractor was not readily available, zero tillage with full rates of herbicides fit very well the farming situation at Rembau. There was variability from farm to farm and over seasons as expected in this kind of on-farm development (Johnstone and Lowther 1993). However, such variability in weed species and pressure, for example, provided valuable insights and new knowledge for increased success rate of technology transfer from research to farmers.

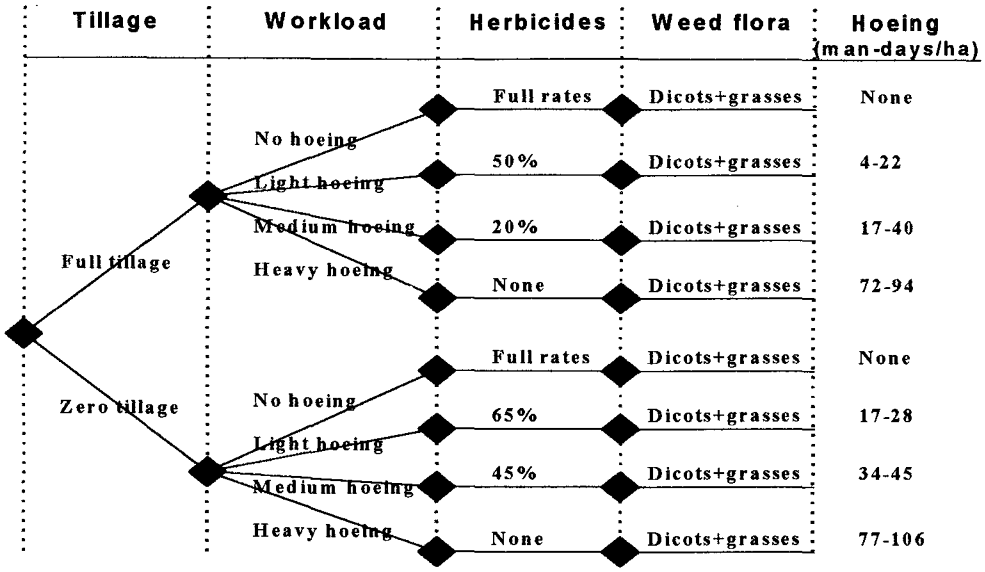


Figure 2. Decision tree to assist farmers and extension officials in deciding the appropriate weed management technique for maize or sweet corn (data from Tables 1 and 3). Full rates of herbicides were 1500 g ai/ha (full tillage) and 2940 g ai/ha including glyphosate+2,4-D BE (zero tillage).

Acknowledgement: We thanked our colleagues in Ciba Basel for reviewing the earlier manuscript.

References

Beets, W. C. (1990). Raising and Sustaining Productivity of Smallholder Farming Systems in the Tropics. AgBe Publishing: Alkmaar, Holland. pp.21-35.

Ebner, L. (1982). Considerations on appriopriate weed control concepts for developing economies in the tropics. *Proceedings of the First International Conference on Plant Protection in the Tropics, Kuala Lumpur.* pp.465-473.

FAO/Unesco/ISRIC (1988). *FAO-Unesco Soil Map of the World; Revised legend.* World Soil Resources Report No. 60. Rome: FAO.

Jonestone, P. D. and W. L. Lowther (1993). Design and analysis of multi-site agronomic evaluation trials. *New Zealand Journal of Agricultural Research* 36:323-326.

Kon, K. F., C. J. Hare, and K. P. Tiw (1992). The role of herbicides for adapted weed management in soil conservation farming. *Proceedings of the First International Weed Control Congress, Melbourne*, pp.257-260.

Kon, K. F. (1993). Weed management: towards tomorrow. *Proceedings of the 10th Australian Weeds Conference and 14th APWSS Conference, Brisbane*, pp.1-9.

Tiw, K. P., J. L. Allard, and K. F. Kon (1994). Weed mangement in full and zero tillage in the tropics: comparative efficency and weed dynamics. *Proceedings of the 4th International Conference on Plant Protection in the Tropics*, pp.228-130.

Zoschke, A., L. Ebner, and M. Quadranti (1990). Soil conservation farming - first experiences in Malaysia. *Proceedings of the Third International Conference on Plant Protection in the Tropics, Genting Highlands.* Vol 6. pp.272-283.

Zoschke, A. (1994). Toward reduced herbicide rates and adapted weed management. *Weed Technology* 8: 376-386.

Weeds as a Production Constraint in the Rainfed Lowland Rice Environment of the Lao PDR

S. Khotsimuang[1], J.M. Schiller[2] and K. Moody[3]

[1]Agronomist, Department of Agriculture and Extension, Vientiane, Lao PDR; [2]Research Programer, Lao-IRRI Project, P.O. Box 4195, Vientiane, Lao PDR; [3]Agronomist, International Rice Research Institute, P.O. Box 933, Manila 1099, Philippines.

Key words: weeds survey, rainfed lowland rice, Lao PDR

Abstract. Rainfed lowland rice cultivation in the Lao PDR which accounts for almost 66% of the rice area and 77% of production, is almost completely non-mechanised and involves very few inputs apart from family labour. In 1993 a survey of 191 farmers was undertaken in nine districts over seven provinces of the Mekong River Valley that comprise about 80% of the rainfed lowland area, on farmer perception of the significance of weeds as a production constraint relative to ten other potential yield limiting factors. In eight of the nine districts covered by the survey, farmers indicated weeds to be among the three most important potential yield constraints (drought and pests were usually ranked as the most important). The most important weed species reported by farmers were the broadleaved weed *Ludwigia octovalvis* (J.) Raven and the sedge *Fimbristylis miliacea* (L.) Vahl; *Marsilea minuta* Presl. was also a common problem weed in southern provinces, while *Xyris indica* Linn. was prevalent in the central region. Manual weed control was practised by all farmers; none reported the use of herbicides. Despite the perceived significance of weeds as a potential yield constraint, the time committed to weed control rarely exceeded 10 days ha^{-1}, with some reporting inputs as little as 2-3 days ha^{-1}. Infertile soils throughout areas under rainfed lowland rice cultivation is believed to be responsible for poor weed growth and the subsequent low labour input for weed control. Farmers generally fail to perceive soil fertility management as an important yield constraint, whereas research has demonstrated potential yield improvements exceeding 100% through improved P and N nutrition. In an improved soil fertility regime, weeds are expected to become a more significant yield constraint.

Introduction

Of approximately 649,000 ha under cultivation in the Lao PDR, about 83% is devoted to rice. Rainfed lowland rice accounts for about 66% of the rice area and 77% of production. Total annual rice production ranges from between 1.5 to 1.6 million tons. In years of normal rainfed the country is generally self-sufficient in rice. However, with more than 97% of the rice area being based on rainfed cultivation, unseasonally dry conditions can result substantial national rice deficits. National policy aimed at improving rice self-sufficiency, is to raise total production to about 2.2 million tons by the year 2,000. Most of this increased production is proposed from the rainfed lowland environment, through a 27% expansion in the area cultivated and a 29% in average yield (Inthapanya et al 1995).

Current rice production in the rainfed lowland environment is based on minimal inputs apart from family labour. Land preparation is still largely undertaken with buffalo drawn plows, fertilizer inputs are minimal (Doungsila et al 1995), little use is made of pesticides (Savongdy et al 1995), weed control is undertaken manually, as are transplanting, harvesting and threshing. Most of the area is still sown to traditional glutinous varieties with about 95% of production being consumed domestically. Many areas where loamy sands and sandy loam soils predominate, have consistent household rice deficits (Phanthavong et al 1994).

To achieve the targeted yield improvements in the rainfed lowland environment of Laos, the adoption of improvements to production technology will be essential. Recommendations have been made for improved varieties (Inthapanya et al 1995), soil fertility management (Lathvilayvong et al 1995), and IPM strategies (Savongdy et al 1995). The significance of weeds as a production constraint in the rainfed lowland environment of Laos has not been quantified. In the upland environment, weed infestation and the resulting labour requirement for their control are major determinants of production, with labor inputs of up to 190 days ha^{-1} not being unusual (Roder et al 1995). The potential significance of weeds in the rainfed lowland rice environment in other parts of Asia has been well documented (Moody et al 1986) with reductions in grain yield of between 10-75% being reported.

A survey to assess farmer perception of the significance of weeds, weed control methodology and inputs, and the main weed species in the rainfed lowland environment of Laos, was undertaken in 1993. This paper reports the results of that study.

Methodology

Approximately 80% of the rainfed lowland rice area is in provinces adjacent to the Mekong River in central and southern Laos, where six major plains are recognised; these are the Vientiane Plain (Vientiane province and Vientiane Municipality), Borikhamxay, Sebang-Faay (Savannakhet and Khammouane provinces), Sedone (Saravane province) and Champassak. These plains are the focus of the Lao government's efforts to raise the level of rice self-sufficiency. Interviews were conducted of 191 farmers in this area, together with Sayabouly province in the western part of central Laos (Figure 1, Table 1).

Significance of Weeds as a Constraint to Rice Production: Farmer respondents were asked to rank the importance of various potential constraints in the rice production cycle; weeds, insect pests, disease, labour availability, weeds, rodents, crabs/snails, drought, flooding, credit availability, and varieties. They were also given the opportunity of listing other possible constraints (in practice none were nominated).

Weeds was ranked among the three most important production constraints in eight of the nine districts surveyed (Figures 2 to 4), although in most instances it was ranked third after drought and pest damage.

Weed Control Methodology and Labour Input: No farmers covered by the survey used herbicides for weed control (in most rural areas of Laos and even provincial towns, herbicides are not commercially available). Hand weeding was practiced in all areas. No mechanical weeders were used apart from hoes or other hand implements. Most respondents reported a labour input of between 4 and 8 days ha^{-1} (Table 1); the maximum labour input reported was less than 12 days ha^{-1}. The period of maximum weeding was 30-40 days-after-transplanting; farmers prefer to wait until weeds reach a certain height before they commence weeding.

Factors Associated with Weed Ingress: Farmers were asked to indicate from a range of choices, those factors which they most associated with weed ingress. Lack of water and/or water management was the most significant factor reported in all areas (Figure 5, Table 2). Years with lower than average rainfall when there are periods with little or no standing water in the rice fields, is always associated with increased weed competition. The role of standing water in suppressing weed ingress and growth is well known and reported (Bhan 1983, Moody et al 1986). The use of organic fertilizers was also usually associated with increased weed competition, as a result of the weed seeds that are usually in such fertilizers; in Laos organic fertilizers are usually based on the use of buffalo manure. The third most common factor associated with weed ingress, that of land preparation, is also well known (Sankaran et al 1988).

Major Weed Species: A total of 19 weed species were reported by farmers (Table 3). However, the important weeds were few, with some regional differences. The broadleaved weed, *Ludwigia octovalvis,* and the sedge, *Fimbristylis miliacea,* were generally the most consistently cited problem weeds; *Marsilea minuta* was also important in southern provinces, while *Xyris indica* was prevalent in the central region. Significant ingress by these weeds was usually within about 30 days following transplanting. Grass weeds were rarely cited as being a problem.

Discussion

Although weeds are cited by farmers as one of the three most important production constraints in the rainfed lowland rice environment of Laos, the fact that they only spend between 4 and 8 days ha^{-1} in manual weed control during the wet season cropping cycle suggests that under the existing production system, farmers are able to manage the weed problem using traditional manual weed control techniques. Rarely are significant wet season weed populations observed in farmer's fields. The association of weed infestation with soil fertility, particularly N levels, is well known (Moody 1982, Bhan 1983). A major reason for low weed infestation levels in the rainfed lowlands of Laos can be attributed to a general low level of soil fertility. Most of the soils throughout the rainfed lowland environment are loamy sands or sandy loams - Alisols, Acrisols, Cambisols and Gleysols (Doungsila et al 1995), with widespread low levels of N,P and sometimes K. For the past 30 years there have been very few nutrient inputs to replace those removed in the form of grain or other agricultural products. Productivity of the system is low. However, the potential for marked improvements in rice yields in response to combined inputs of N and P has been demonstrated in many provinces of the central and southern agricultural regions (Lathvilayvong 1995). Significantly increased weed ingress is usually observed in association with these nutrient inputs under on-farm experimental conditions.

Although the rainfed lowland rice production system in Laos is expected to remain a low input system for the forseeable future, government efforts to raise national rice productivity through a combination of higher yields and expanded cropping area in the rainfed lowland environment, will necessitate substantially higher fertilizer inputs, particularly of N and P. Some of the N requirements may be able to be met through the use of green manure crops (Lathvilayvong et al 1995). However, P inputs will be required through the use of inorganic fertilizers (Doungsila 1995). Increased significance of weeds can be expected to be associated with these increased fertilizer inputs. However, it is unlikely that weed infestation levels will be achieved that will result in a high demand for herbicides. Farmer income levels are expected to also remain low, placing continued reliance on family labour for most production operations. Although direct seeding is not yet practiced, if adopted as a drought avoidance strategy in the rainfed lowland environment (Lao-IRRI 1994), weed competition and its control can be expected to receive increased attention.

Acknowledgement

Weeds research currently being undertaken within the Lao National Rice Research Program, is mainly financed by the Swiss Development Cooperation (SDC), through the Lao-IRRI Project.

References

Bhan V.M. 1983. Effects of hydrology, soil moisture regime, and fertility management on weed populations and their control in rice. *In* Weed Control in Rice, p 47-56. Los Banos, Laguna, International Rice Research Institute, Philippines.

Doungsila, K., J.M. Schiller, T. Phommasack, and V. Manivong. 1995. Soil phosphate status and fertilizer use in the Lao PDR. Paper presented at International Workshop on Direct Application of Phosphate Rock and Appropriate Technology Fertilizers in Asia - What Hinders Acceptance and Growth, 20-24 February 1995, Kandy, Sri Lanka. 15 p.

Inthapanya, P., J.M. Schiller, S. Sarkarung, T. Kupkanchanakul, and V. Phannourath. 1995. Varietal improvement strategies for the rainfed lowland environment of the Lao PDR : 1995-2000. Paper presented at International Rice Research Conference, 13-17 February 1995, IRRI, Philippines. 17 p.

Lathvilayvong, P., J.M. Schiller, T. Phommasack and T. Kupkanchanakul. 1995. Nutrient management in the rainfed lowland rice environment of Laos. Paper presented at International Rice Research Conference, 13-17 February 1995, IRRI, Philippines. 14 p.

Lao-IRRI Project. 1994. National Rice Research Program, 1993 Annual Technical Report, 255 p.

Moody, K. 1982. Weed control in sequential cropping in rainfed lowland rice growing aras in tropical Asia. *In* Weed Control in Small Farms, p 49-62. Honolulu, Hawaii, Asian-Pacific Weed Science Society.

Moody, K., S.K. De Datta, V.M. Bhan, and G.B. Manna. 1986. Weed control in rainfed lowland rice. *In* Progress in Rainfed Lowland Rice, p. 359-370. Los Banos, Laguna, International Rice Research Institute.

Phanthavong, S., J.M. Schiller, and V. Sipaphone. 1994. Applied farming systems research in the rainfed lowlands of the Lao PDR. Paper presented at Third Asian Farming Systems Symposium, 7-10 November 1994, Manila, Philippines. 17 p.

Roder, W., S. Phengchanh, S, Maniphone, K. Songnhikongsuathor, and B. Keoboualapha. 1995. Weed management strategies aimed at reducing labor for upland rice production. Paper presented at the International Rice Research Conference, 13-17 February 1995, IRRI, Philippines. 16 p.

Sankaran, S., K. Moody and C. Chandrangsu. 1988. Weed management in rainfed lowland and upland rice based farming systems. Paper presented at International Rice Research Conference, 7-11 November 1988. 23 p.

Savongdy, H., J.M. Schiller, and H.R. Rapusas. 1995. Pesticide use and IPM research in the Lao PDR. Paper presented at International Training Course and Workshop on the Evaluation of Pesticides Effects on Natural Enemies, 13-26 March 1995, MARDI, Malaysia. 14 p.

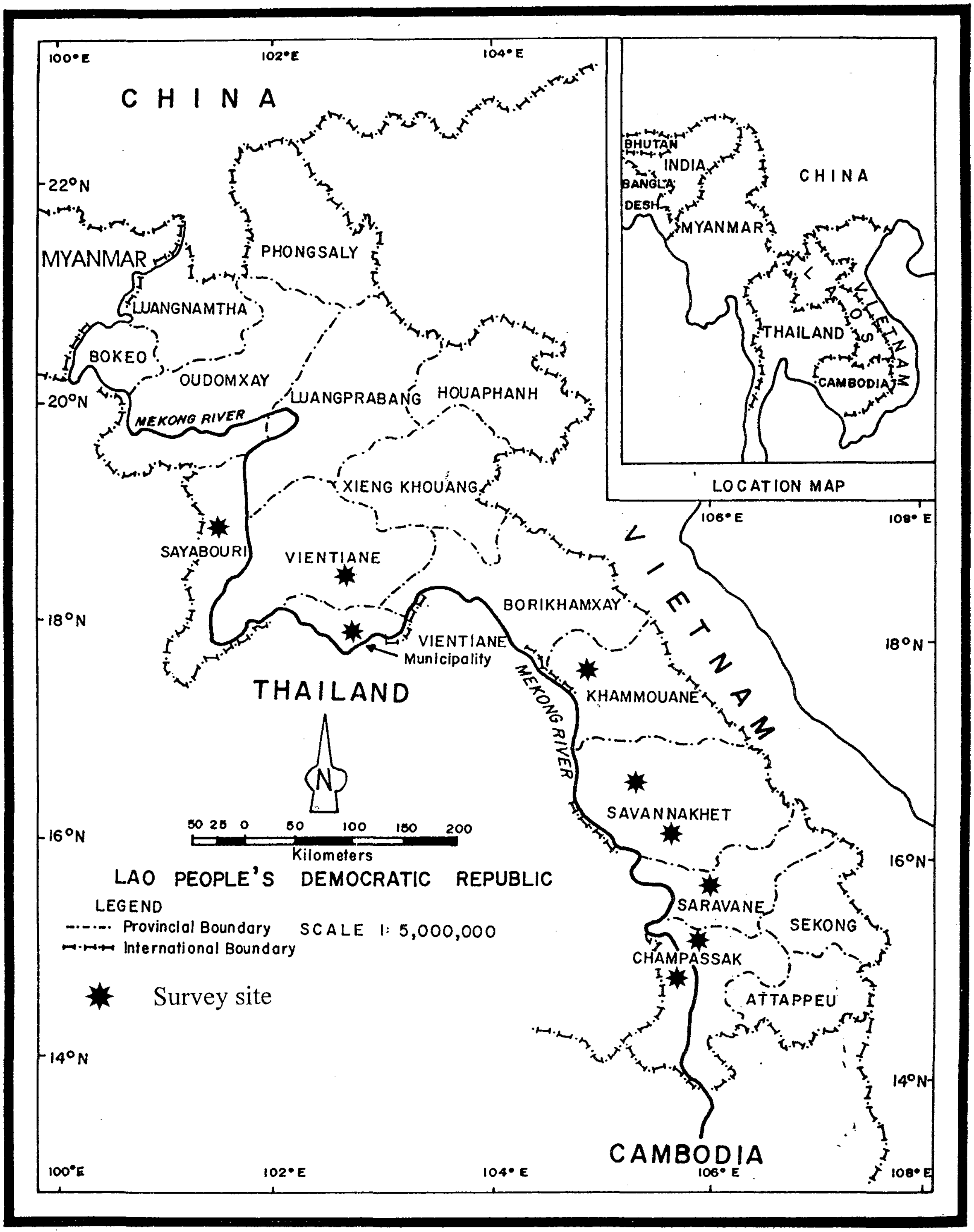


Figure 1 : Distribution of weed survey sites

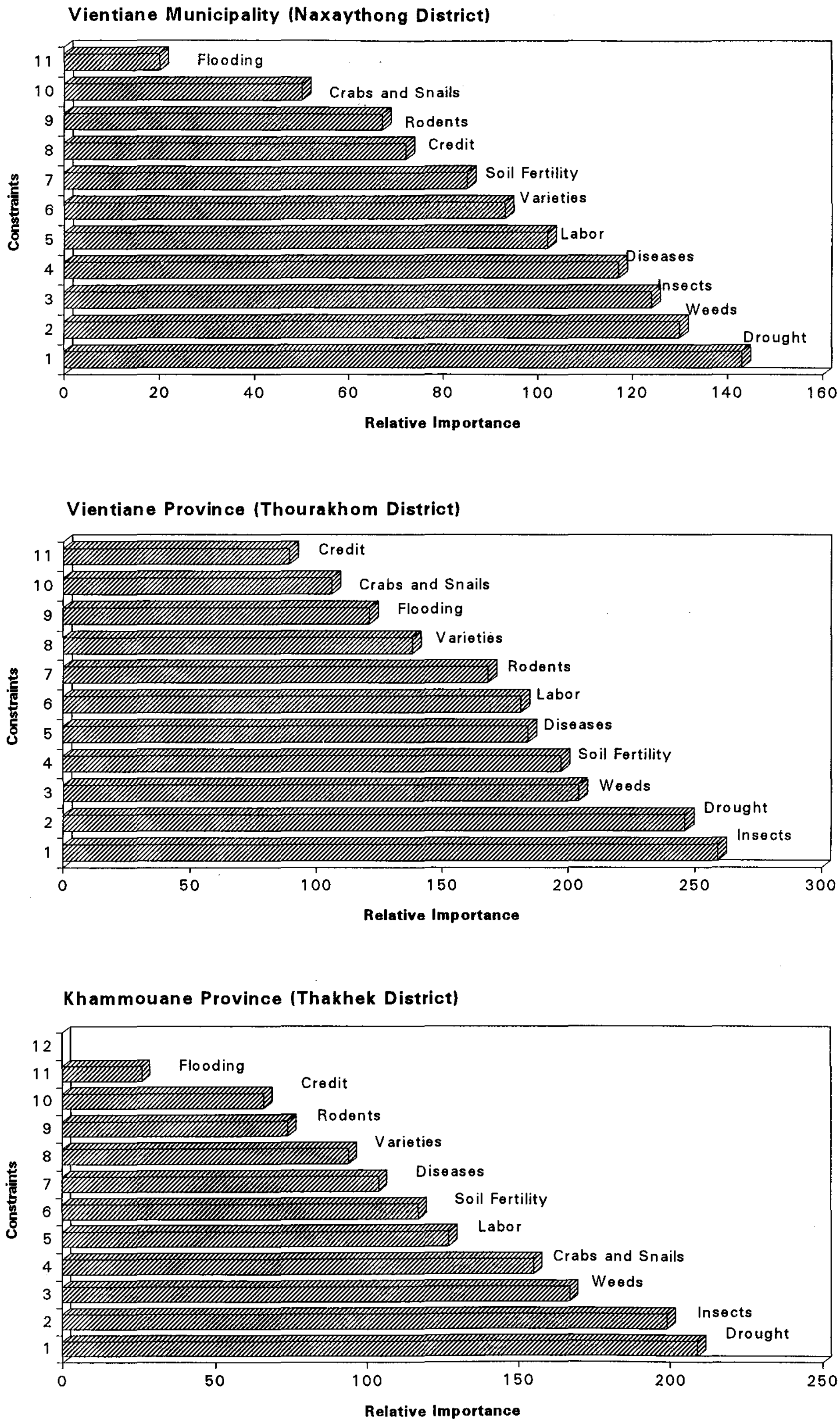


Figure 2 : Farmer perception of production constraints in Vientiane Municipality, Vientiane and Khammouane provinces

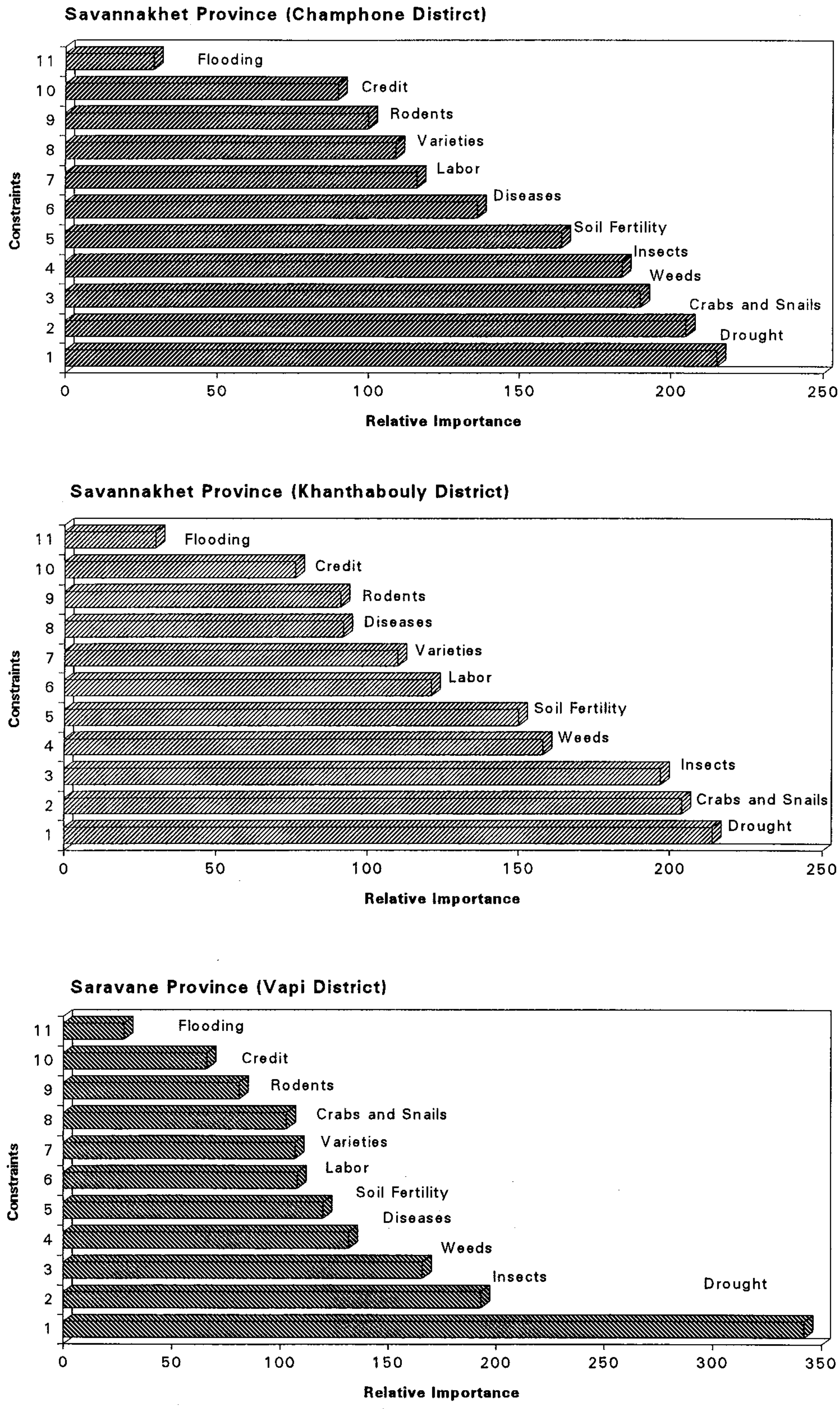
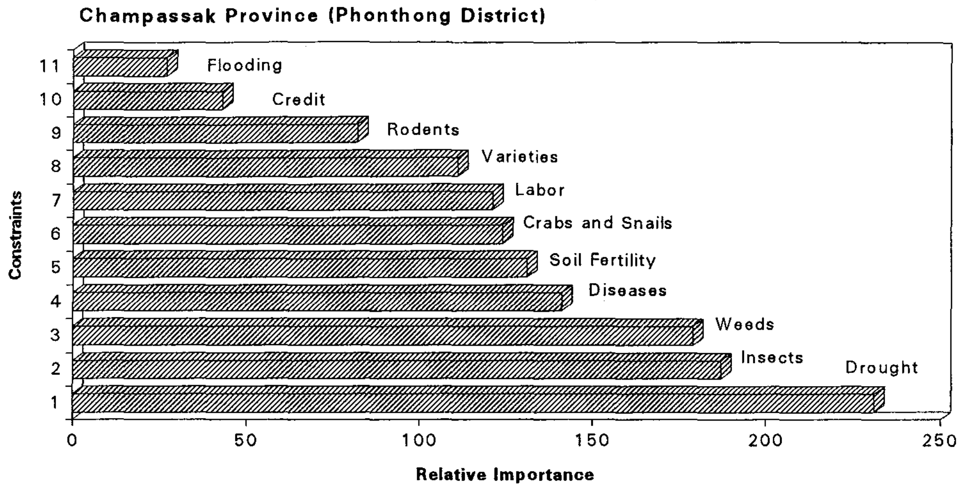
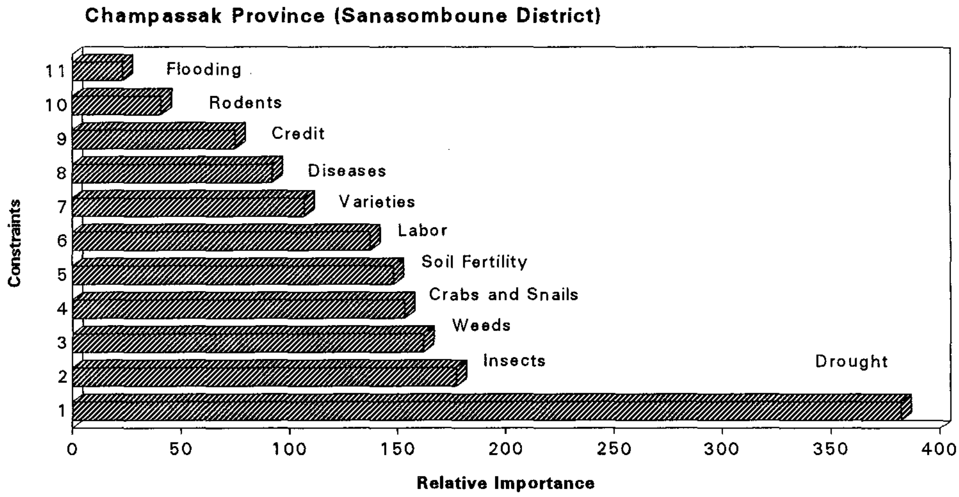


Figure 3 : Farmer perception of production constraints in Savannakhet and Saravane provinces





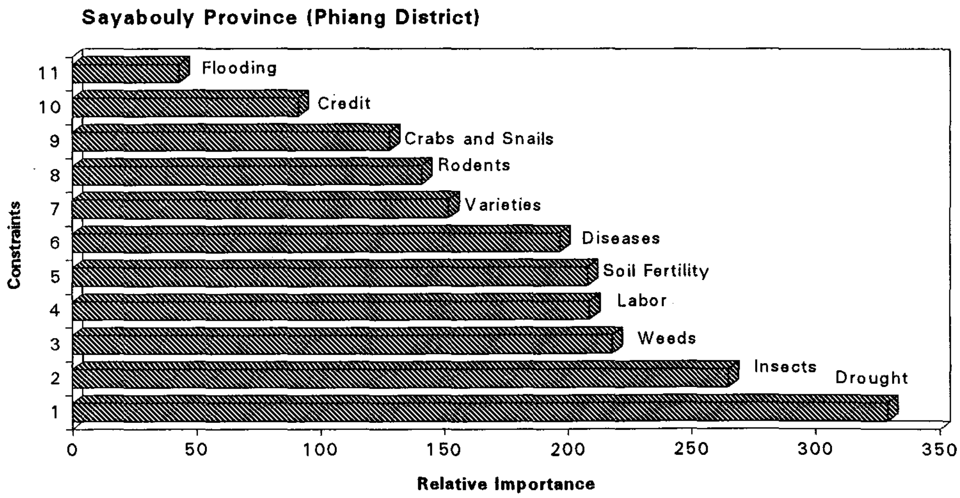


Figure 4 : Farmer perception of production constraints in Champassak and Sayabouly provinces

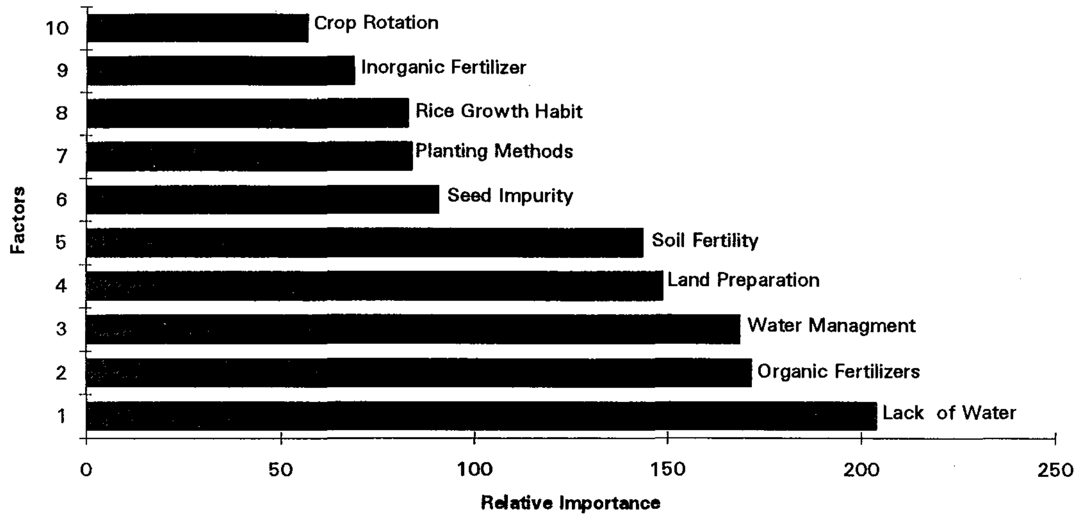


Figure 5 : Factors associated with weed ingress - total survey area

Table 1 : Distribution of survey and assessment of labour input for weed control

	Province	District	Village	Households interviewed	Labour Input days ha^{-1}
1.	Vientiane Municipality	Nasaythong	Pakhaed	5	11.5
			Nakhunnoi	5	4.8
			Namkian	5	8.1
2.	Vientiane	Thurakhom	Phonethong-Nafaay	15	3.9
			Narong	14	4.6
3.	Khammouane	Thakhek	Nadinchi	10	3.9
			Thahae	10	6.5
4.	Savannakhet	Khanthabouly	Phonesim	11	7.0
			Thatinghang	11	3.7
		Champhone	Phalaeng	12	7.0
			Dongnakhoy	12	5.8
5.	Saravane	Vapi	Saphat	10	8.4
			Phakkha	10	4.3
6.	Champassak	Sanasomboune	Saphay	10	10.7
			Donphek	10	2.8
		Phonethong	Oupalath	11	2.3
			Phonesan	10	2.2
7.	Sayabouly	Phiang	Nasing	10	7.5
			Nadarn	10	4.7
			Phiang	10	10.0

Table 2 : Most important factors associated with weed ingress

Province	District	Factors associated with for Weed Ingress 1	2	3
Vientiane M.	Nasaythong	lack water	organic fert.	water manag.
Vientiane P.	Thurakhom	land prepn.	organic fert.	lack water
Khammouane	Thakhek	lack water	water manag.	organic fert.
Savannakhet	Champhone	lack water	organic fert.	water manag.
Savannakhet	Khanthabouly	soil fert.	organic fert.	lack water
Saravane	Vapi	lack water	organic fert.	land prepn.
Champassak	Sanasombourne	lack water	organic fert.	land prepn.
Champassak	Phonethong	lack water	water manag.	land prepn.
Sayabouly	Phiang	lack water	water manag.	land prepn.

Table 3 : Occurrence and importance of weed species according to province

Scientific Name (common name)	Location (Province)						
	Vientiane M.	Vientiane	Khammouane	Savannakhet	Saravane	Champassak	Sayabouly
Annual grasses :							
- *Echinochloa colonum* (L.) Link (bird rice)	–	–	–	*	–	–	–
- *Rottboella exaltata* Linn. f. (corngrass)	**	**	*	–	–	*	–
- *Ischaemun rugosum* Salisb. (wrinkle duck beak)	–	–	–	–	–	*	***
Perennial grasses :							
- *Leersia hexandra* Sw. (swamp ricegrass)	–	–	–	–	–	–	*
Annual sedges :							
- *Fimbristylis miliacea* L.(lesser Fimbristylis)	***	–	***	**	**	**	–
- *Cyperus iria* L. (umbrella sedge)	–	*	–	–	–	–	–
- *Cyperus difformis* L. (small flower umbrella plant)	–	–	–	–	–	–	**
- *Scirpus supinus* L.	**	–	**	–	–	–	***
Perennial sedges :							
- *Cyperus rotundus* L. (purple nutsedge)	–	–	–	–	–	–	*
- *Scirpus grossus* Linn. f.	–	–	–	*	–	–	*
- *Eleocharis dulcis* (Burm f.) Henshel (water chestnut)	*	*	–	–	–	–	–
- *Eleocharis spiralis* R. Br.		**	–	–	–	–	–
Annual broadleaved :							
- *Ludwigia octovalvis* (Jacq) Raven (water primrose)	***	***	–	***	***	***	**
- *Monochoria vaginalis* (Burm. f.) (monochoria)	*	*	–	–	–	*	–
- *Limnocharis flava* Buch.	–	–	–	–	–	–	*
Perennial broadleaved :							
- *Ludwigia adscendens* (L.) Hara (creeping water primrose)	–	–	–	*	–	–	–
- *Mimosa pudica* L. (sensitive plant)	*	*	–	–	*	–	–
Miscellanneous :							
- *Marsilea minuta* Presl. (water-clover)	*	*	*	*	**	**	*
- *Xyris indica* Linn. (yellow-eyed grass)	*	**	**	**	–	**	*

*** Present and major problem ** Present and important * Present but not important

Noxious Weeds and Their Control in Sri Lanka

W.M.D.Wasala

Horticultural Crop Research and Development Institute
Gannoruwa, Peradeniya, Sri Lanka.

Abstract. Problem weeds in rice *Echinochloa* spp. and *Ischaemum rugosum*. Salib., are controlled by either manual or chemical means. Though propanil is commonly used, recently sethoxydim and fenoxaprop-p-ethyl and mixtures of propanil with pre-emergent herbicides have been used instead. In highlands, perennials Purple nutsedge (*Cyperus rotundus* L.), *Panicum repens* L. and bermudagrass [*Cynodon dactylon* (L.) Pers.] predominate owing to the continuous use of the hand hoe (mammoty). In recently developed and abandoned agricultural lands in the Dry and Intermediate zones, cogongrass [*Imperata cylindrica* (L.) Beauv], Guineagrass (*Panicum maximum* jacq) and *Pennisetum polystachyon* (L.) Schult. are abundant. The management practices adopted are burning, use of the hand hoe and application of paraquat. Avenue planting of legumes *Gliricidia sepium* Jasq. and *Leucaena leucocephala* (Lam.) De wit. resulted in weed shift from problem weeds to manageable weeds. While cogongrass is found in all plantation crops, *Chromalaena odorata* (L.) King & Robinson., *Mikania scandens* (L.) Willd and *P. polystachyon* are the noxious weeds under coconut. Mechanical weeding, intercropping, cover crops and occasional use of herbicides are practiced in rubber and coconut lands, whereas in tea, use of paraquat, glyphosate and oxyflourfen is common. Noxious aquatic weeds are *Salvenia molesta* Mitchell. and water hyacinth [*Eichhornia crassipes* (Mart.) Solms]. Biological control of *Salvenia* with *Cyrtobogous salveniae* Clader and sands. is fairly effective.
Key words. Noxious, Weeds, Control, Sri Lanka

INTRODUCTION

Agroecology of Sri Lanka

Sri Lanka is an island between 6° and 10° north of the equator. Its land area of 6.56 m ha is divided in to three major climatic zones based on the rainfall as wet zone (>2250mm), intermediate zone (1500-2250 mm) and dry zone (900-1500 mm). Rain fall which has a bimodal distribution is received mainly during the two monsoons, North East from October to February (Maha) and South West form April to September (Yala). The country is divided into three as low country (0-300 m), mid country (300-1000 m) and upcountry (>1000 m) based on elevation. These zones further subdivided into 24 agroecological zones considering amount and distribution of rain fall, elevation and soil types.

As the noxious weeds vary in occurrence in different cropping situations, this paper discuses these situations and methods employed for their control.

WEEDS AND THEIR CONTROL IN DIFFERENT FARMING SITUATIONS

Rice

Although commonly found weeds in rice fields have been ranged from 70 to 80, the number of weeds present in a given field may not exceed fifteen and out of which only four to five have direct influence on rice yields (14). Majority of weeds found in wetland rice belong to families Poaceae and Cyperaceae (Table,1). The most common grass species are *Echinochloa* spp, *Ischaemum rugosum* Salib. and *Isachne globosa* (Thunb) Kantze. The widespread sedges are *Cyperus iria* L., *Cyperus difformis* L., and *Fimbristylis miliacea* (L.) Vahl. (2). Among the few important broad leaf weeds *Monochoria vaginalis* (Burm.f.) Kunth. and four *Ludwigia* spp. Usually grass weeds are more prominent in the dry zone whereas sedges and broad leaf weeds are dominant in the wet zone. Chandrasena, 1987 reported that *Ischaemum rugosum* has achieved a greater prominence compared to other common weeds in low country wet zone . *Limnocharis flava* (L.) Buchen. is another weed commonly found in wet zone fields. In some areas *Commelina diffusa* Burm.f. shows a fairly high frequency (11).

Dryland rice cultivation commences with dry land preparation followed by dry seeding. The fields are subsequently flooded with rains. Therefore initial problem weeds do not remain throughout the growing season. Apart from the annuals, perennials such as bermudagrass [*Cyanodon dactylon* (L.) Pers.] and *Panicum repens* L. become a serious problem at the early stage of dryland rice, but when fields are flooded these weeds get gradually disappeared. However these weeds grow again at the end of rice crop. Some of the weeds reported in early stage of dryland rice are *Aeschynomene* spp., *Acanthus llifolius*, *Cleome viscosa* L., and *Mimosa pudica* L.(11).

Land preparation of wetland rice can destroy considerable amount of weeds and provide a weed free seed bed. Some farmers apply paraquat to reduce weed pressure to facilitate ploughing operations. Transplanted rice occupies about 25% of the total extent where weed problem is relatively low, hand weeding is a common practice which combines with flooding. Use of mechanical weeders are rare.

Most of farmers (80%) in high yield potential area in dry zone apply herbicides. Major herbicides used are propanil and MCPA. Propanil has been reported to be ineffective in some areas resulting lower application rates. Use of this chemical is limited in the Wet zone due to frequent rains prevail and the inability to drain the fields when critical period for herbicide is due.

Though several pre-emergent and early post-emergent herbicides have been tested and recommended for rice (Table,4), their farmer acceptance is rather poor. This appears to be due to initial phytotoxicity to rice seedlings though the symptoms recover in time (17). Combination of pre-emergent herbicides with propanil provide a weed control for an extended period as they are effective against emerged weeds as well as lately emerging weeds. Such formulations presently being used are thiobencarb + propanil (Satunil), oxadiazon + propanil (Ronstar PL) and butachlor + propanil (Butanil). The recently introduced herbicides fenoxaprop-P-ethyl (Whip super) and sethoxidim (Nabu-S) are used in very low rates.

Table 1: Weed species commonly found in paddy fields.

Weed species	Family
Grasses	
Echinochloa crusgalli (L.) Beauv.	Poaceae
Echinochloa colonum (L.) Link.	"
Ischaemum rugosum Salisb.	"
Isachne globosa (Thumb.)Kuntz.	"
Leptochloa chinensis (L.)Nees.	"
Sedges	
Cyperus iria L.	Cyperaceae
Cyperus difformis L.	"
Cyperus haspun L.	"
Cyperus pilosus Vhal.	"
Fimbristylis milliacea (L.)Vhal.	"
Broad leaf weeds	
Monochoria vaginalis (Burm f)Kunth.	Pontederiaceae
Commelina diffusa Burm f.	Commelinaceae
Ludwigia spp.	Onagraceae
Limnocharis flava (L.)Buchen.	Butomaceae
Aeschynomene aspera L.	Fabaceae
Lindenia spp.	Scrophulariaceae

Source: Chandrasena, 1987., Amarasighe, 1985, Weerakoon and Gunawardene, 1983

Subsidiary food crops and vegetables

Cereals such as maize and millets, grain legumes such as cowpea, mungbeen, soybeen and black gram are mainly grown during maha season in rainfed uplands in dry and intermediate zones and vegetables are distributed throughout the country. Under the traditional slash and burn system weeds are not a serious problem. When crop yields declined mainly due to weeds farmers shifted to new lands. Abandoned agricultural lands are dominated by guineagrass [*Panicum maximum* Jacq.], cogongrass [*Imperata cylindrica* (L.) Beauv.] and *pennisetum polystachyon* (L.) Schult. In addition *Chromalaena odorata* (L.) King & Robinson., *Lantana camera* L. and *Mikania scandens* (L.) Willd. are commonly grown. Presently this system does not prevail in large scale due to scarcity of lands. The annual grass species, goosegrass [*Elusine indica* (L.) Gaertn.], *Echinochloa colonum* (L.) Link., *Digitaria* spp., *Dactyloctenium aegyptium* (L.) Beauv., *Brachiaria* spp. and broad leaf weeds

Euphorbia spp, *Tridax procumbens* L.,*Ageratum conyzoides* L.,*Boerhavia erecta* L.,*Amaranthus* spp.,*Mimosa pudica* are common weeds in highland areas (Table,2). The dominant weed in recently developed upland areas under Mahaweli Irrigation system is cogongrass. Fields with long history of cropping have been invaded by purple nutsedge [*Cyperus rotundus* L.],and bermudagrass (15). Though it is reported that imazapyr followed by tillage eradicate cogongrass,it is not being used (16).
The major methods of weed control in these crops are hand pulling, scraping and earthing up with mammoty which resulted in developing weeds with under ground vegetative organs namely purple nutsedge, *Panicum repens* and bermudagrass. One of the severe problem reported in cassava is penetration of tubers by rhizomes of *Panicum repens* (3). During the dry season burning is used as a prelude to land preparation which is common in lands infested with cogongrass and guineagrass. Use of herbicide in cereals and legumes is rare, however chemical control is practiced to a certain extent in crops like onion, potato and carrot (Table,5).
Experiments with agro forestry systems in the dry zone indicated that tree legumes *Gliricidia sepium* Jacq. and *Leucaena leucocephala* (Lam.) De wit planted in avenues resulted in weed shift from problem weeds to easily manageable species (18).

Fruit Crops

Most of the fruit crops, except pineapple and banana, are grown in small scale. Pineapples are widely distributed in coconut growing areas which usually intercropped with banana or cassava. Perennials, *Panicum repens*, purple nutsedge, *Chromalaena odorata*, *Mimosa pudica, Lantana*, and *Mikania scandens* are some of the problem weeds reported. Mammoty weeding is done in controlling weeds in fruit crops. Mulching with coir dust (10-15 cm) is common in most pineapple cultivations. Herbicides diuron, paraquat and glyphosate are applied in controlling weeds in pineapple and in other fruit crops.

Table 2 : Common weeds in subsidiary food crops and vegetables

Weed species	Family
Grasses	
Elusine indica (L.)Guertn.	Poaceae
Echinochloa colonum (L.)Link.	"
Digitaria spp.	"
Dactyloctenium aegyptium (l.)Beauv	"
Panicum repens L.	"
Imperata cylindrica (L.)Beauv.	"
Cyanodon dactylon (L.)Pers.	"
Sedges	
Cyperus rotundus L.	Cypereceae
Broad leaf weed	
Euphorbia spp.	Euphorbiaceae
Amaranthus spp.	Amaranthaceae
Tridax procumbens L.	Asteraceae
Mimosa pudica L.	Pabaceae
Ageratum conyzoides L.	Asteraceae
Boerhavia erecta L.	Nyctaginaceae
Cleome vicosa L.	Capparidiaceae
Vernonia cinerea (L.)Lees	Asteraceae

Source: Wasala, 1990, Siriwardene and Amarasinghe, 1982.

Plantation crops

Plantation in Sri Lanka consists of 0.22 m ha of tea 0.19 m ha of rubber and 0.14 m ha of coconut (1). Wide spaced planting due to steep land and pruning of tea produce more exposure of ground which create heavy weed growth. Use of implements to remove weeds in tea is not advocated at present as it enhance soil erosion. Therefore hand pulling of weeds is recommended leaving about 25% of small weeds such as *Oxalis* spp., *Drymaria cordata* (L.) Willd. ex R.& S and *Centella asiatica* (L.) Urb. to prevent soil erosion. Several chemicals have been recommended (Table,4). Continuous application of herbicides has resulted build up of resistant weed types. For example, *Borreria latifolia* (Aubl.) K. Schum. has build up resistance due to continuous use of paraquat in low country while *Erigeron sumatrensis* Retz. and *Crassocephalum crepidiodes* (Benth.) S. Moore. have shown some resistance buildup to 2,4 D in most of the tea plantations (6).

Weed control is specially important in young rubber. In addition to weeding with mammoties the use of cover crops like *Pueraria* and *Desmodium* and controlled grazing by livestock are effective in suppressing weed growth(12). Chemical weed control is not common in rubber except for the occasional use of Paraquat and glyphosate. In coconut, cogongrass, *Chromalaena odorata*, *Mikania scandens* and *Mimosa pudica* are some of the problem weeds (Table,4) competing for nutrients. Besides, they obstruct manuring and harvesting. *Mikania* is a wine which can block light when grown around the coconut seedlings. Mechanical and cultural methods employed in controlling weeds are scraping, slashing, ploughing in between coconut rows and use of live mulches with *Pueraria phasioloids* Benth., *Calapogonium mucunoides* Desv. and *Centrosema pubesence* Benth.(7). Sequential cropping of cassava, sweetpotato and *Colocasia* combined with manual weeding in each crop showed best results in weed control (8). Total weed killers are used occasionally. Biological control of *Chromalaena odorata* in coconut lands by defoliator *Pareuchaetes pseudonsulata* has been tried (7).

In sugarcane perennials such as guineagrass, cogongrass, yellow nutsedge and *Panicum repens* are reported to be problem weeds. Control is achieved by mechanical means and using herbicides like paraquat, glyphosate and diuron (10).

Table 3 : Common weeds in plantation crops.

Weed species	Family
Tea	
Imperata cylindrica	Poaceae
Panicum repens	,,
Borreria spp.	Rubiaceae
Pennisetum spp.	Poaceae
Crassecephalum crepidoldes (Benth.)	Asteraceae
Erigeron sumatrensis(Retz.)	,,
Drymaria cordata	Caryophyllaceae
centella asiatica	Apiaceae
Ipomoea spp.	Convolvulaceae
Mikania Scandens	Asteraceae
Rubber	
Imperata cylindrica	Poaceae
Mikania scandens	Asteraceae
Pennisetum spp.	Poaceae
Axonopus Spp.	,,
Paspalum spp.	,,
Chromalaena odorata	Asteraceae
Hedyotis spp.	Rubiaceae
Coconut	
Impereta cylindrica	Poaceae
Chromalaena odorata	Asteraceae
Mikania scandens	,,
Pennisetum polystachyon	Poaceae
Panicum repens	,,
Chrysopogon aciculatus (Retz.) Trin.	,,
Stachytarpheta indica	Verbenaceae
Sida spp.	Malvaceae
Mimosa pudica	Fabaceae
Cynodon dactylon	Poaceae

source: Gunathilaka,1992. Samarappuli, 1992. Lukshmi, 1993.

Table 4: Herbicides used in Sri Lanka.

Herbicide	Crop
2,4 D	Rice,tea
2,4 D+piperophos	Rice
Alachlor	Chilli,legumes,onion,maize,groundnut
Amttryn+atrazine	Sugarcane.
Butachlor+propanil	Rice
Diuron	Pineapple,sugarcane
Penoxaprop-p-ethyl	Rice
Glyphosate	Total
MCPA	Rice
Methabenzthiazuron	Onion,grain legumes
Metalochlor	Onicn
Metribuzin	Potato,carrot
Napropamide	Chilli
Oxadiazon+propanil	Rice,
Oxyfluorfen	Rice,tea,maize,legumes
Paraquat	Total
Pretilachlor	Rice
Propanil	Rice
Thiobencarb+propanil	Rice
Quinchlorac	Rice
Sethoxydim	Rice

Source:Registrar of pesticides,Sri Lanka.
Herbicides recommendation, Department of Agriculture.

Weeds in irrigation systems

Salvenia molesta Mitehell. and water hyacinth [*Eichhornia crassipes* (Mart.)Solms.] are the major weeds found in reservoirs (5). Grasses, *Brachiaria mutica* (Forsk.) Stapf., *Panicum repens*, and cogongrass are found on the banks of irrigation cânals. *Typha latifollia, Jussia repens* L., water hyacinth and *Limnocharis flava* usually colonize the shallow edges of the water bodies. guineagrass and cogongrass may also colonize on the canal banks. A fairly successful control of *Salvenia* have achieved through the released biological parasite *Cyrtobogus salveniae* Clader. and Sands.

CONCLUSION

Major competitive weeds in rice are grasses specially *Echinochloa* spp. and *Ischaemum rugosum*. As such combination of chemical and cultural methods of weed control has to be strengthen to reduce weed pressure on rice. Most of the upland cropping lands are invaded by few perennials with underground vegetative organs namely purple nutsedge, *Panicum repens* and bermudagrass. It is therefore advisable to employ a weed management system to control these weeds and shift the weed population towards a more easily manageable set of weeds.

Priority should be given to control aquatic weeds as they may become serious weeds in paddy fields. In addition monitoring of weed flora in areas where biological control of *Salvenia* is being practice is important to understand the weed shift in the place of *Salvenia*.

The type of noxious weeds are varied according to the cropping situation. However some weed species like *Panicum repens*, cogongrass, and purple nutsedge , bermudagrass, *Chromalaena odorata, Mikania scandens* and guinea grass are troublesome in most situations while some of them are limited to specific areas.

REFERENCES

1 Agricultural statistics of Sri Lanka (1992). Department of Census & Statistics. Ministry of policy planing & implementation

2 Amarasinghe, L. (1985) Rice weeds in Minor tank paddy fields and their effect on crop yields.Krushi 7 (4) 17-24.

3 Bandara,W.M.S.M.and K.P.U.De Silva, (1989). Relationship between tuber damage and dry matter accumulation in cassava (Manihot esculenta Cranz.). Proc.Sri Lanka Association for the Advancement of Science.

4 Chandrasena ,J.P.N.R.(1987). Rice field weeds in Colombo and Gampaha Districts of Sri Lanka .J. Natn. Sci.Coun. Sri Lanka. 15 (2) 249-265.

5 Dassanayake,M.D. (1973). Noxious aquatic vegetation control in Sri Lanka.in Aquatic weeds in South East Asia.Proc. Regional seminar on aquatic vegetation. New Delhi. 12-17 Dec. 59-61.

6 Ekanayake,P.B. (1992). Current status on weed management in tea plantations of Sri Lanka. Tropical weeds Vol. 1 (1). 16-23.

7 Gunathilaka,H.A.G. (1992). Current status and future needs in weed research in coconut in Sri Lanka. Tropical weeds. Vol.1 (1). 30-39.

8 Jayakody,D.P.P, S.L.Ranamukaarachchi and H.P.M.Gunasena (1991). Weed dynamics and crop yields in cassava based intercropping under coconut. Trop. Agric. Res. 3: 195-215.

9 Lukshmi,M.M.S.D.(1993). Studies on biology and management of *Crassocephalum crepidoldes* Benth.and *Erigeron sumatrensis* (retz.) in high grown tea. M pill Thesis , Post Graduate Institute of Agriculture, Peradeniya, Sri Lanka.

10 Mettananda,C (1990). Sugarcane growing in Sri Lanka.SRI publication No: 2 79-93.

11 Rochecouste,E. (1979). Strengthening plant protection service phase 2 (Res.) Weed control in agricultural crops. UNDP-FAO Rep. Sri Lanka.

12 Samarappulli,L (1992). Weed management in rubber plantations. Tropical weeds, Vol.1 (1). 24-29.

13 Siriwardene,T.G.D.,L.Amarasinghe.(1982).Review of yield loss studies in different crops in Sri Lanka.Report of a work shop on cropping system research in Asia.

14 Velmurugu,V.(1980). A review of weed control in rice .Rice Symposium. 1980, Dept.of Agric. Sri Lanka.

15 Wasala W.M.D.,S.D.G.Jayawardene, K.P.Premaratne and F.R. Bolton. (1990). Problem weeds in rainfed upland Maize cultivation in Mahaweli system C .Sri Lanka Asso. Adv. Sci. 46 th sessions.

16 Wasala,W.M.D.(1989). Upland Weed Management in Mahaweli system-C. M phil Thesis, Post Graduate Institute of Agriculture, Peradeniya, Sri Lanka.

17 Wasala,W.M.D.,S.D.G.Jayawardene and R.S.R.P.Pathirana. (1985). Chemical weed control in broadcast rice. Proc.Sri Lanka Asso. Adv. Sci. 41 st Session - 24.

18 Weerakoon,W.L.and S.D.I.E.Gunawardena, (1983). Rice field weed flora of Sri Lanka. Trop. Agric. 139: 1-14.

19 Witharama,W.R.G. (1987). Ally cropping under *Gliricidia* and *Leucaena*.Mahaweli system- C. M phil Thesis, Post Graduate Institute of Agriculture, Peradeniya, Sri Lanka.

Author Index

15TH CONFERENCE • TSUKUBA, JAPAN •
APWSS

THE ASIAN-PACIFIC WEED SCIENCE SOCIETY
THE WEED SCIENCE SOCIETY OF JAPAN
THE JAPAN ASSOCIATION FOR ADVANCEMENT OF PHYTO-REGULATORS