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PREFACE

This Proceedings is the compilation of invited and contributed papers to the ninth Asian-Pacific Weed Science Society Conference at Philippine Plaza, Manila, Philippines on November 28 to December 2, 1983. Included are papers presented during the conference and those papers submitted before the deadline but were not presented due to certain reasons.

Abbreviations used in the text are explained at the end of the Proceedings.

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SOME MECHANISMS TO ENHANCE FOLIAR ABSORPTION OF HERBICIDES[1]

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ABSTRACT

Rainfall hampers the effectiveness of postemergence herbicides in the tropical wet season. This paper considers the influence of rainfall on reducing herbicide performance and selected practical methods to improve absorption of postemergence herbicides. These methods include the use of surfactants, oils, salt and phosphate ester additives and low volume — high concentrate applications of herbicides.

INTRODUCTION

During the wet season, the effectiveness of postemergence herbicides in the tropics is often hampered by rainfall, which washes off herbicides from leaf surfaces. This paper will consider the effect of rainfall and some methods to circumvent this problem.

One way to cope with rainfall is to enhance the rate of absorption of foliar-applied herbicides, enabling sufficient herbicide to be absorbed before rainfall. Alternatively, film-forming substances or other additives may be used to retard waash-off. However, there are few studies on these film-forming substances and those indicate limited success (Hull 1970). Thus this paper will address selected methods to improve foliar absroption of postemergence herbicides. An increased rate of absorption may render postemergence herbicides more effective, or reduce the amount needed for weed control and thereby increase the number of situations where more expensive herbicides can be utilized economically. The paper is not intended to provide an exhaustive review of the subject; its intent is to highlight certain aspects of this topic.

EFFECT OF RAINFALL ON REDUCING HERBICIDE PERFORMANCE

While rainfall shortly after application reduces the effectiveness of post-emergence herbicides, there are considerable differences in the extent of reduced activity depending on the herbicide, formulation, and weed species.

The effect of rainfall was illustrated by Weaver *et al.* (1946) with the amoonium salt of 2, 4-D (2, 4-dichlorophenoxy) acetic acide applied to soybean (*Glycine max* (L.) Merr. 'Hodgson') and bean (*Phaseolus vulgaris* L.). In greenhouse studies, 6 hours of elapsed time was necessary between application and onset of artificial rain (25 cm in 5 minutes) in order to avoid a reduction of 2, 4-D activity. In field studies with soybean, artificial rainfall (1.3 cm in 13 minutes) reduced 2,4-D activity even when rainfall was applied 24 hours after herbicide application. Using the herbicide bentazon (3-isopropyl-1H-2,1,3-benzothiadiazin-(4) 3H-one 2,2-dioxide) Doran and Anderson (1975) also found that rainfall reduced the herbicide effect more in the field than in the greenhouse. A number of other studies demonstrated the effects of rainfall in reducing herbicidal activity (Elle 1952, Brun *et al.* (1961).

Rainfall would be expected to influence the activity of different formulations differently. Behrens and Elakkad (1981) showed that the activity of the butoxyethanol ester of 2,4-D (oil-soluble) was reduced much less by rainfall than the alkanolamine salt of 2,4-D on velvetleaf (*Abutilon theophrasti* Medic), lambsquarters (*Chenopodium album* L.), wild mustard (*Brassica kaber* (DC.) L.C. Wheeler var. *Pinnatifida* (Stokes) L.C. Wheeler, soybean and redroot pigweed (*Amaranthus retroflexus* L.). This response would be expected since the alkanolamine salt is more soluble in water. However, when Upchurch *et al.* (1969) compared the effect of simulated rainfall on an ester and an amine salt of 2,4,5-T(2,4,5-trichlorophenoxy) acetic acid) applied to woody species such as turkey oak (*Quercus lacvis* Walt.) and red maple (*Acer rubrum* L.), there was little difference between formulations. Virtually no reduction in herbicidal activity occurred with either formulation even when simulated rainfall occurred 5 minutes minutes after application.

A water-soluble herbicide that rainfall would have little effect on is paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) because of rapid absorption. This was shown in studies by Bovey and Davis (1967) and Bovey and Diaz-Colon (1969). However, they showed considerable differences in species response to wash-off of paraquat. When washed severely (2.5 cm in 1 minute) paraquat activity was reduced substantially on guava (*Psidium guajava* L.) if washing occurred as late as 2 hours after application; but only very slightly on mango (*Mangifera indica* L.) even when washing occurred 1-2 minutes after application (Bovey and Diaz-Colon 1969). Perhaps this difference contributes to the relative susceptibility of these two species to paraquat (guava is relatively tolerant).

Differences in species response to the amount of water for wash-off may relate to the leaf surface morphology. Behrens and Elakkad (1981) applied 0.1 to 1.5 cm of simulated rain within 1 minute to five species treated with two 2,4-D formulations. The species with hairy leaves, such as soybean and velvetleaf generally required a greater rainfall volume to reduce the herbicidal effect.

Thus rainfall is a critical determinant for effectiveness of postemergence herbicides; the extent of reduced herbicidal activity depends on the type of herbicide, formulation, and weed species.

SURFACTANTS AND OILS

Surfactants enhance absorption and activity of foliage-applied herbicides. Although a number of reviews have addressed this topic (Foy and Smith 1969, Hull 1970, Robertson and Kirkwood 1969, Hodgson, 1982) few studies have considered using surfactants as a way to increase herbicide effectiveness when rainfall occurred shortly after herbicide application.

Behrens and Elakkad (1981) compared the effect of rainfall on the activity of 2,4-D alkanolamine salt and 2,4-D butoxyethanol estr with and without a surfactant (alkylarylpolyoxyethylene glycol) on five species. In general, the surfactant resulted in a reduced detrimental effect of rainfall on the alkanolamine salt of 2,4-D. Because the butoxyethanol ester of 2,4-D was much more resistant to the effect of rainfall, it was difficult to show any differences caused by the surfactant. Indeed, in the case of soybean, the surfactant appeared to increase the effect of rainfall by reducing the activity of the 2,4-D ester activity. In a study with the sodium salt of bentazon, Doran and Andersen (1975) showed that a surfactant did not consistently reduce the effect of rainfall. Surfactant reduced the effect of rainfall in only one of three experiements; in two experiments, the surfactant did not overcome the detrimental effect of rainfall. Surfactants may have opposing effects; it may increase the rate of absorption, but because it reduces surface tension, herbicide remaining on the leaf surface may wash-off easier with rainfall.

Oils have shown to have a substantial effect in reducing the effect of rainfall on herbicidal activity. Weaver et al (1946) applied 2,4-D acid in a non-emulsifiable oil formulation and showed that rainfall applied as early as 15 minutes after application did not reduce its activity. Applications in other undiluted oil formulations (Leonard 1958, Holstun and Bingham 1960, Barrentine and Warren 1970, Burr and Warren 1971) would be expected to produce similar results.

Application of water-soluble herbicides in emulsifiable oil may also be a useful method to reduce the effect of rainfall. Bentazon applied with emulsifiable vegetable or petroleum oil was more effective than bentazon with no oil in reducing the detrimental effect of rainfall on velvetleaf and common cocklebur (*Xanthium pensylvanicum* Wallr.) (Doran and Andersen 1975) as well as redroot pigweed (Nalewaja *et al.* 1975).

Although emulsifiable oil appears useful for enhancing herbicide activity, its use may cause a reduction in activity of some herbicides as shown by Suwunnamek and Parker (1975) with glyphosate (N-(phosphonomethyl) glycine) on purple nutsedge (*Cyperus rotundus* L.). Similarly herbicidal activity of emulsions of glyphosate solubilized in oil, was lower than the conventional aqueous formulations (Turner and Loader 1974, Casely *et al.* 1976).

Turner and Loader (1974) indicated that application of glyphosate solubilized in oil was much more effective than glyphosate in aqueous solutions with surfactant or with emulsified oil. The solubilized oil formulation may also help reduce the detrimental effects of rainfall. However, the high cost of solubilization may make this development impractical.

SALT AND PHOSPHATE ESTER ADDITIVES

The use of cheap salt additives to enhance herbicidal activity appears to be an attractive method to reduce the amount of herbicide necessary to control weeds, and consequently the cost of weed control. Furthermore, if these salt additives increase the rate of absorption, they may serve as a means to reduce the detrimental effect of rainfall. Numerous studies have established that various additives, especially ammonium salts and phosphates enhanced the activity of foliage-applied herbicides (Table 1).

Enhancement of herbicidal activity of these foliage-applied herbicides has generally occurred with water-soluble materials. Turner and Loader (1972a) showed that S,S,-butyl phosphorotritioate (DEF) enhanced activity of the inorganic salt or amine formulations of picloram (4-amino-3,5,6-trichloropicolinic acid), 2,4,5-T or mecoprop (2-(4-chlro-*o*-tolyl)oxy) proprionic acid) but not with the ester formulations of these herbicides. Enhancement of MCPA (((4-chloro-*o*-tolyl)oxy) acetic acid), activity by ammonium salts on poplar (*Populus gelrica* Ait.) occurred with the salt formulation but not the ester formulations (Turner and Loader 1972a). However, not all water-soluble herbicides are enhanced by these additives. For instance, Turner and Loader (1975) were not able to enhance paraquat activity on guava (*Psidium guajava* L.), poplar and privet (*Ligustrum ovalifolium* Hassk.) by additions of phosphate or ammonium salt additives.

The mechanism of action of these additives is not clear. DEF is an effective defoliant with rapid contact action (Brun *et al.* 1961) and was observed to cause a swelling and eventual bursting of epidermal cells within a few minutes after application. In reviewing some of their recent work, Turner (1972) indicated that there is evidence that DEF facilitated the foliar entry of water soluble growth regulator herbicides (Turner and Loader 1970, 1971). Since DEF was expensive, Turner (1972a) suggested that tributyl phosphate and the mixed butyl acid phosphates (BAP) be considered for practical use since these produced similar results as DEF when

Table 1. Summary of enhancement of herbicidal activity or absorption by salt or phosphate ester additives.

Herbicide	Enhancement material	Reference
ENHANCEMENT OF HERBICIDAL ACTIVITY		
amitrole	tributyl phosphate, mixed butyl acid phosphates	Turner and Loader 1975
	ammonium sulfate, mixed butyl acid phosphates	Blair 1975
	ammonium nitrate, ammonium thiocyanate	Babiker and Duncan 1975
asulam	tributyl phosphate, urea	Babiker and Dunkan 1975
dalapon	sodium, potassium, lithium	
	sulfates, phosphates, nitrates	McWhorter 1971
	phosphate ions	Wills 1971
	potassium phosphate	McWhorter and Jordan 1976
2,4-D	ammonium phosphate, ammonium nitrate	
	ammonium sulfate, potassium phosphate,	
	orthophosphoric acid, ammonium potassium phosphate	Sexsmith 1953
	ammonium ethanolammonium	Orgell and Weintraub 1957
	ammonium sulfate, ammonium nitrate	Borodina *et al.* 1962
glyphosate	potassium, sodium, ammonium, calcium, phosphate	Wills 1973
	ammonium sulfate, tributyl phosphate,	
	mixed butyl, acid phosphates	Turner and Loader 1975
	ammonium sulfate, mixed butyl acid phosphates	Blair 1975
	ammonium sulfate, ammonium phosphate	
	ammonium butylphosphate, urea	Suwunnamek and Parker 1975
	ammonium sulfate	Lutman and Richardson 1977
	amoonium sulfate	Turner and Loader 1980

Table 1. Continued

MCPA	ammonium nitrate	Turner andLoader 1972 b
micoprpo	tri-S-butyl phosphorotrithioate	Truner and Loader 1970, 1971
	ammonium nitrate, ammonium sulfate, ammonium chloride, ammonium citrate	Turner and Loader 1972b
MSMA	sodium, potassium, lithium sulfates, phosphates, nitrates	McWhorter 1971
	monovalent ammonium, potassium	Wills 1971
NAA	most ammonium ions	Horsfall and Moore 1964
picloram	tri-s-butyl phosphorotrithioate	Turner and Loader 1970
	tributyl phosphate, mixed butyl acid phosphates trimethyl phosphates	Turner and Loader 1972a
	ammonium sulfate, ammonium nitrate	Turner and Loader 1972b
	ammonium sulfate	Wilson and Nishimoto 1975a
2,4,5-T	tri-S-butyl phosphorotrithioate	Turner and Loader 1970, 1971, 1972a
DNOC	ammonium sulfate	Harris and Hyslop 1942
		Crafts and Rieber 1945
ENHANCEMENT OF HERBICIDE ABSORPTION		
2,4-D	ammonium nitrate, sodium monohydrogen phosphate	Szabo and Buchholtz 1961
picloram	various ammonium salts	Wilson and Nishimoto 1975a, 1975b
2,4,5-T (ester)	phosphoric acid, ammonium nitrate	Brady 1970

added to picloram and mecoprop. However, no leaf injury was observed with these acidic phosphate esters and their mode of action may be different.

Although most workers showed an enhancement of activity by additions of ammonium, phosphate or other salts, only a few attempted to measure penetration through a leaf surface or a membrane. Penetration of Sedum epidermis, bean and sunflower (*Helianthus annuus* L.) leaves by 2,4-D ethanolamine salt with ammonium and phosphate ions was greater than by 2,4-D alone (Szabo and Buchholtz 1961). Ammonium nitrate and phosphoric acid enhanced absorption of the isooctyl ester of 2,4,5-T by tree leaves (Brady 1970). Enhanced absorption of the potassium salt of picloram by ammonium sulfate was shown on bean, guava and strawberry guava (*Psidium cattleianum* Sabine) (Wilson and Nishimoto 1975a). Ammonium sulfate, chloride, nitrate and phosphate enhanced picloram absorption by detached leaves of strawberry guava (Wilson and Nishimoto 1975b).

Szabo and Buchholtz (1961) showed that there was no enhancement of 2,4-D penetration by phosphate as sodium monohydrogen phosphate or ammonium as ammonium nitrate into bean or sunflower leaves at pH 3; however at pH 5, both ammonium and phosphate ions increased 2,4-D penetration substantially. Cobaltous, ferrous, manganous and zinc as nitrates and cupric as sulfate did not enhance penetration with either species at pH 5. Penetration through Sedum epidermis with or without these ions was always less at pH 5 than at pH 3.

Low pH favors the formation of the undissociated acid of anionic herbicides such as the phenoxys, glyphosate, picloram and dinoseb, and therefore materials lowering the pH of the spray solution with these herbicides would be expected to enhance penetration through the cuticle.

In attempting to elucidate the nature of ammonium sulfate enhancement of picloram absorption, Wilson and Nishimoto (1975b) conducted studies with detached leaves of strawberry guava. Using the method of Sargent and Blackman (1962) the magnitude of the ammonium sulfate enhancement was not different from the enhancement due to low pH (4). Furthermore ammonium monohydrogen phosphate (pH 4.6) and ammonium dihydrogen phosphate (pH 7.7) increased picloram absorption equally despite pH differences. Potassium monohydrogen phosphate (pH 7.7) did not enhance picloram absorption whereas potassium dihydrogen phosphate (pH 4.6) enhanced absorption to about one-half the absorption from the ammonium phosphates. Thus while the magnitude of the ammonium effect appoximates the pH effect, the ammonium enhancement occurs at higher pH levels as well.

Despite the enhancement in absorption of herbicides by inorganic salts, there sometimes appears to be no increase in the amount of translocated. This was shown by Brady (1970) who increased foliar absorption of 2,4,5-T by four tree species with ammonium nitrate, but the amount translocated to the roots was not different from the 2,4,5-T applied alone in three of the four species. The addition of ammonium sulfate enhanced picloram absorption in strawberry guava and the amount of picloram that translocated acropetally reflected the increased absorption (Wilson and Nishimoto 1975a). However, despite an increased absorption of picloram with the addition of ammonium sulfate by guava leaves, there was no increase in picloram translocation.

EFFECT OF DILUENT VOLUME OF HERBICIDAL ACTIVITY

Recently, in studies with glyphosate, there has been fairly consistent evidence that low volume applications of glyphosate were more active than higher volume applications of glyphosate (Upchurch *et al.* 1972, Riemer 1973, Phillips 1975, Fernandez and Bayer 1977, Sandberg *et al.* 1978, Stahlman and Phillips 1979, Jordan 1981, Kawate 1983). These effects have also been shown for technical grade dalapon on johnsongrass (*Sorghum halepense* (L.) Pers.) (McWhorter 1963) and phenoxy herbicide phytotoxicity to peas (*Pisum sativum* L.) (Sesmith 1954, Buchholtz 1954). as well as 2,4-D on rice (*Oryza sativa* L.) and celosia (*Celosia argentea*) (Vega and Obien 1963).

Divalent and trivalent cations antagonize glyphosate activity (Phillips 1975, Riemer 1973, Sandberg *et al.* 1978, Selleck 1980, Stahlman and Phillips 1979). At higher diluent volumes, a greater amount of cations in proportion to glyphosate was present, thus a reduction of glyphosate activity was possible. Such a reduction in glyphosate activity was shown by comparing a normal water source with distilled or deionized water (Selleck and Kline 1978, Stahlman and Phillips 1979, Selleck 1980) or by adding complexing agents (Turner and Loader 1978). However, the enhanced low volume effect occurred in the absence of these cations, Sandberg *et al.* 1978, an Stahlman and Phillips 1979 and Selleck 1980.

Since surfactant concentration increases when glyphosate is applied as Roundup™ in lower diluent volumes, it is possible that the increased surfactant concentration was causing the increased activity at lower diluent volumes. Riemer (1973) found that the addition of 1% surfactant to the glyphosate solution completely restored the activity on phragmites (*Phragmites communis* Trin.) lost by increasing the volume rate from 187 to 748 L/ha. Similarly, Baird and Begeman (1972) found that diluent volume did not influence glyphosate activity on quackgrass when the surfactant concentration was held constant. However, increased surfactant may not always completely restore the loss of activity due to the increased diluent volume. This was shown by Sandberg *et al.* (1978) on tall morning glory (*Ipomoea purpurea* (L.) Roth.) and Jordan (1981) on bermudagrass (*Cynodon dactylon* (L.) Pers.).

In some cases, the low diluent volume effect was extremely striking. For example, less activity on bermudagrass was obtained when Fernandez and Bayer (1977) applied 1.8 g/L glyphosate at 373 L/ha (671 g glyphosate/ha) than 3.6 and 5.4 g/L glyphosate solutions applied at 94 L/ha (338 and 507 g glyphosate/ha), despite the fact that more glyphosate per unit area was being applied at the higher diluent volume.

The penetration of a chemical through the cuticle occurs by diffusion (Franke, 1967). Thus application of higher concentrations of an herbicide on the cuticle surface would enhance penetration. Application of lower diluent volumes might be one easy way to accomplish this. Where investigators have used relatively large drops (1 ul range), more glyphosate actitivy was obtained increasing the concentration of the drop than by increasing the number of drops (Ambach and Ashford 1982, Kawate 1983). Erickson and Duke (1981) showed that 14C-methyl glyphosate movement across isolated quackgrass (*Agropyron repens* (L.) Beauv.) cuticle increased almost linearly with increased glyphosate concentration.

In the past, many investigators considered spray volume, droplet size, droplet concentration and droplet distribution, particularly with the phenoxy herbicides. These investigators considered droplet sizes normally observed in typical sprayers (100u to 1000u) in contrast to the studies cited with glyphosate using large drops (1 to 5ul). However, there appears to be contradictory evidence on this topic. For example, Smith (1954) and Fisher and Young (1950), found larger droplets to be effective while Ennis and Williamson (1963), Vega and Obien (1963), Hurtt et al. (1969), Way (1969), McKinlay *et al.* (1972), McKinlay *et al.* (1974) found smaller drops to be more effective than larger drops. Furthermore, Behrens (1957) found drop size to have little effect. Douglas (1968) found that an increase in droplet diameter from 250u to 500u increased diquat activity on broad bean (*Vicia faba* L.) and decreased diquat activity beyond 500u up to 1000u. Similar results were obtained with paraquat with its optimum drop diameter at 400u. This is in contrast with the study of McKinlay *et al.* (1978) with paraquat, where a 100u drop diameter was more phytotoxic than a 350u drop diameter. Behrens (1957) varied droplet size of 2,4,5-T without the influence of droplet spacing by varying herbicide concentration and spray volume. Under these conditions small and large drops of 2,4,5-T were equally effective on mesquite (*Prosopis* sp.) and cotton (*Gossypium* sp.). However these factors are all interrelated since spacing is directly correlated to droplet size when the volume remains constant.

Although it is difficult to completely sort out these differences, high concentrations of 2,4-D can kill or injure tissues beneath the absorbing area, reduce translocation out of this area and thereby reduce activity. Furthermore, very small drops may drift away from the target leaf and thereby cause differences in response.

All studies appear to agree that enhanced external concentration on the leaf surface will enhance herbicidal absorption. With certain herbicides such as the phenoxys that may potentially kill cells beneath the absorbing area of some species, a low volume — high concentrate application may not necessarily be the best practice. All evidence to date does not indicate that rapid cell death does not occur beneath the absorbing area for glyphosate.

In summary, while there may be some practical use for these low-cost mechanisms to enhance absorption of postemergence herbicides, these practices will not work universally. It is hoped that this presents some perspective on the status of this topic.

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CONTROL OF AQUATIC WEEDS IN SOUTHEAST ASIA

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ABSTRACT

There is an increasing awareness of the problem of aquatic weeds in Southeast Asia due to the increasing effort in the management of water resources.

Mechanical, chemical and biological control have been used against aquatic weeds. So far mechanical control is still the most common practice.

Chemical control should be done carefully since the water resources in many cases are used for several purposes such as fishery, irrigation and drinking water source. There is too little information on the application of herbicides in open water, therefore it is necessary to develop techniques to apply herbicides in open water and to study new herbicides which can be used under Southeast Asian condition.

It is also a necessity to explore the potential of biological control in Southeast Asia.

Future control measures of aquatic weeds should be properly planned and consistently applied. It should consider economic, sociological as well as ecological aspects.

INTRODUCTION

Reports of other workers show that aquatic weed problems are rapidly increasing throughout Southeast Asia. Pancho and Soerjani (1978) recorded a 112 species of aquatic weeds in Southeast Asia. The Southeast Asian Workshop on Aquatic Weeds held in Malang, Indonesia in June, 1974, identified the most ten serious aquatic weeds in the region. Listed were waterhyacinth (*Eichhornia crassipes* (Mart.) Solms, water fern (*Salvinia molesta* D.S. Mitchell), water lettuce (*Pistia stratiotes* L.), hydrilla (*Hydrilla verticillata* (L.f.) Royle, *Nelumbo nucifera* Gaerta, *Scirpus grossus* L.f., *Panicum repens* L., *Typha angustifolia* L., *Monochoria vaginalis* (Burm. f.) c. Presl., *Salvinia cucullata* Roxb. ex Bory. Among them waterhyacinth is the most noxious occuring in all country members. Water fern was ranked as second after waterhyacinth although it occurs only in Indonesia, Singapore and

Malaysia (Soerjani and Pancho, 1974). Recently giant mimosa (*Mimosa pigra* L.) is reported as a serious problem in Northern Thailand.

Aquatic weed infestation is stimulated by the eutrophication of the water bodies as a result of nutrient accumulation from domestic waste, urban and rural drainage and industrial and agricultural run off. It is recognized that nitrogen and phosphorus are the essential elements responsible for excessive growth of aquatic weeds.

There is an increasing awareness of the problems of aquatic weeds infestation due to the increasing effort in the management of water resources. In Southeast Asia, aquatic weeds interfere with drainage systems, hydroelectric schemes, fishing and recreation, navigation and irrigation. The problems are diverse. The degree of harmful effects depends on the type of water habitats and the problem varies in each country.

MECHANICAL CONTROL

Mechanical control includes cutting and removal of the aquatic weed mass from the water body. It can be done by manual removal with handheld tools or with machinery. Manual control is the most common method used in Southeast Asia, the labor-rich countries. Fully mechanized method is very expensive since it employs sophisticated tools.

Cutting may even stimulate plant growth. It allows the remaining plants to regenerate faster due to a decrease in density of the population. Mechanical control does not leave any residual effect, however, it should be applied frequently and is, therefore, costly.

Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms is the most noxious aquatic weed in Southeast Asia. In Thailand waterhyacinth infests canals, road side ditches, lakes and also water sources in various parts of the country. In small water bodies, the plants are pulled from the water by grapples or elevator. The mass is processed by the local municipality as compost or swine feed. In Kwan Phayao natural water resources, where the water area is covered heavily with waterhyacinth and floating weeds, control is done mechanically. The local government organizes a plan to clean up the lake. Volunteers load their boats with aquatic weeds then the mass is removed from the water and utilized for compost and animal feed. The people use an easy mechanical way by grapples and dragging to the shore. All expenses are paid for by special municipal funds. At Bhumipol dam, one of the largest dams in Thailand, aquatic weeds are dragged ashore by boats. The mass is left to dry on the shore when water level recedes (Chomchalow and Pongpangan, 1974).

Giant mimosa (*Mimosa pygra*) has recently become a noxious weed in Northern Thailand. The plant is growing at the marginal areas of canals, rivers and road sides. It can thrive on dry land, swamps, rivers and lakes up to 3 to 4 m water depth (Shibayama *et al.*, 1982). The major problem created by giant mimosa in Thailand is obstructing the water flow of the irrigation system. Giant mimosa is currently harvested by the villagers along the rivers and from nonagricultural areas for use as fire wood.

Giant mimosa which grows along the Royal Irrigation Department Systems is controlled by cutting (approximately three times per year). Maintenance of traditional irrigation systems is carried out from one to three times per year depending on the characteristics of the individual canal system. Cutting is done by the farmers on a voluntary basis. Thus cutting alone does not achieve permanent control due to the regrowth ability of the shoot (Suwunamek, 1982).

In Malaysia, waterhyacinth, water fern and hydrilla are reported to be major aquatic weeds infesting the country. No data are reported on the coverage by these weeds. However, most of the water areas are infested by one or the other weeds. Compared to some other countries, problems arising from infestation by this aquatic weed are relatively less acute except in areas where irrigation projects are being implemented. Mechanical harvesting and manual clearing are still carried out to control waterhyacinth in irrigation canals and drains. The Public Works Deparment undertakes the responsibility for clearing all waterways which may affect their road or bridges while the Drainage and Irrigation Department is responsible for irrigation canals and drains. The result is not satisfactory. Weed growth is temporarily interrrupted by either slashing or removal by pulling the weeds bodily. Millions of Malaysian ringgit have been spent each year for maintenance of the waterways concenred (Cheam, 1974; Abdullah, 1983).

In Indonesia aquatic weed problems were noticed since 1932 in Rawa Pening lake, Central Java. Mechanical control was started in 1932 until 1942 and afterwards stopped. Besides waterhyacinth, floating islands have created a serious problem in Rawa Pening lake also. Sedges, grasses, shrubs and other woody plant grow on them. Efforts to control these floating islands constitute cutting and discharging them over the dam during the peak of the wet season (February to July) (Soerjani, 1975).

Large scale mechanical control involving 212 hectares was done in 1963 by a civic mission of the army. After six months the area infested increased to 400 hectares. Manual control included cutting, removal and transport of waterhyacinth to the dumping grounds. This method was quite expensive. Four hundred people working for seven to eight hours a day could remove only one hectare (Soewardi and Utomo, 1978). In Rawa Pening lake, mechanical removal of waterhyacinth and floating island is probably the best control method although it is very expensive. Participation of the farmers and villagers increases their income.

Mechanical control is also done in Curug reservoir, West Java and Brantas river and the reservoirs. The water surface of Curug reservoir is covered by aquatic weeds mostly water fern, waterhyacinth and hydrilla. It seems that mechanical control is not frequently done since reinfestation occurs within short periods of time (Nurhali, 1981).

Brantas river and its reservoir in East Java is maintained by Brantas Project in East Java. Some of their reservoirs such as Selorejo, Karangkates and other smaller lakes have a problem of water fern and waterhyacinth. Manual control is done periodically by Brantas Project but it is very laborious (Nguyen, 1973). In one of the Brantas reservoirs, Wlingi Raya reservoir preventive measure was done before the reservoir was filled in 1977. There was a campaign for waterhyacinth eradication at the neighboring areas and also direct information to the farmers and the people around the reservoir about the bproblem and the harmful effect of aquatic weeds. Immediately after the reservoir was filled a bunch of waterhyacinth still entered the reservoir. At the end of 1980 waterhyacinth control was done as a routine practice (BIOTROP, 1980).

The work which is done in Wlingi Raya reservoir indicated that a few plants of waterhyacinth could easily infest the reservoir. The quantity of waterhyacinth biomass trapped in rivers flowing to Wlingi Raya reservoir is estimated to be more than 10 tons. Their entry to the reservoir is prevented by the installation of devices which are cleaned weekly. However, with increasing cost of maintenance some trapping devices will have to be infrequently attended to and the danger of aquatic explosion could be expected (Tjitrosoedirdjo & Wiroatmodjo, 1983). The 0.25 g/week relative growth rate of waterhyacinth in Wlingi Raya reservoir was extremely high. It means that to double this vegetation only 3 weeks are required. It explains why monthly control of waterhyacinth is necessary. Based on our recent work, BIOTROP has recommended alternatives to control waterhyacinth in Wlingi Raya reservoir (Tjitrosoedirdjo & Wiroatmodjo, 1983).

In Singapore aquatic weeds are within the limited reservoirs and agricultural land. The extent of infestation is minimal. Although the problem of aquatic weeds does occur in inland ponds, erservoirs, streams and waterways, it has not become widespread because of preventive measures. In Singapore, the reservoirs are the largest bodies of water. Aquatic weeds are intensively managed and controlled by manual or sometimes mechanical dredging (Seow &Tay, 1974).

Mechanical control of aquatic weeds is always costly and monetary return is low. Utilization of aquatic weeds must be developed. Utilization will decrease management cost and increase the income of the villagers and farmers. Waterhyacinth is successfully applied as animal feed in Thailand, Malaysia and Indonesia. Hydrilla is also harvested by the villagers in Rawa Pening lake for animal feed. The stalk of waterhyacinth is utilized for handicraft in the Philippines. Utilization campaign in Indonesia was done by the Ministry of Public Works and BIOTROP at the place near Rawa Pening lake in 1979 and at Rawa Bureng in East Java in 1980. Booklets containing instructions on the use of water hyacinth were distributed and various ways of utilizing aquatic weed were demonstrated, i.e. for fertilizer, biogas, handicraft, paper pulp production, mushroom culture, etc. (Soerjani, 1979; BIOTROP staff , 1980).

The rapid expansion of rubber and oil palm industries in Malaysia over the last two decades had given rise to serious environmental pollution. They produce about 187,000 tons of biological oxygen demand (BOD) per year. Waterhyacinth can be used to markedly reduce the pollutant level of rubber factory effluent and palm oil mill effluent (John, 1983; Abdullah, 1983b). by using a 10 day retention, 43% total solids, 79% suspended solids, 92% COD, 98% BOD, 50% ammoniacal nitrogen & 56% total nitrogen were removed from the undiluted raw effluent from block rubber factory (John, 1983).

In some transmigration areas in Indonesia the available water resources are not suitable for drinking water, due to low pH, high content of Fe^{++}, Mn^{++}, high content of humic acid which color the water into blackish brown. Conventional method of water treatments such as application of lime, sand etc. are unpractical since the areas are lacking in thesematerials. Currently biofiltration technique is being investigated for its possible adoption in the problem area using waterhyacinth, hydrilla, *Ipomoea aquatica*, *Phragmites* sp. etc. These weeds could reduce the level of turbidity, color, salinity chloride, iron, manganese & sulfate ion. (Wiroatmodjo *et al.*, 1981).

CHEMICAL CONTROL

The problem which arises from the use of chemicals to control weeds in water is the persistence of the chemical. It may prevent the use of the water for particular purposes for certain periods of time. This depends on the rate of application and on the toxicity of its products. Another problem is the death of large amounts of aquatic vegetation which may cause deoxygenation of water (Mitchell, 1978).

In Southeast Asia chemical control using herbicides is practiced in limited scale. There are quite a few herbicides that can be used to control aquatic weeds effectively under tropical conditions. Choice will depend on the weed population, the environmental conditions and the use of the water. The priority given to a particular herbicide over the others is a matter of cost, effectiveness and local concern (Soerjani, 1977).

In Thailand at Borapet lake, 2, 4-D, and silvex are used to control aquatic weeds. The results were favorable only to broadleaved species such as waterhyacinth. At Ubolratana reservoir, 2, 4-D is used to control waterhyacinth. Diquat is used to control free floating species such as duckweed (*Lemna* sp.), water lettuce and water fern at the rates of 1 to 1.7 kg per ha.

Most broadleaved,emerged herbaceous and woody plants can be controlled by single or repeated application of 2, 4-D or silvex at the rate of 2 to

10 kg/ha. These include alligator weed (*Alternantera philoxeroides* (Mart.) Griseb, water smartweed (*Polygonum* sp.) and water primrose (*Ludwigia* spp.) (Chomchalow & Pongpangan, 1974).

In Indonesia chemical control is not done widely, it is used only occasionally.

Chemical control was done in Rawa Pening lake in 1951 until 1956 with 2, 4-D. Due to lack of herbicides the waterhyacinth was left undisturbed from 1956 until 1962. Later, chemical control using 2,4-D was only additional to mechanical control.

In 1970 weeds in Kerinci lake were chemically controlled using 2,4-D.

In the Curug reservoir and lake Jepara (South Sumatera) waterhyacinth was controlled with a mixture of paraquat and 2,4-D (Anwar *et al.*, 1974). After controlling waterhyacinth in the Curug reservoir, the population declined but water fern & hydrilla replaced waterhyacinth. Water fern dominated the water surface soon after.

Soerjani (1983) reported some herbicides which can be used for aquatic weed control such as ametryn at 2 to 6 kg/ha for waterhyacinth and water fern; cyanatryn at 0.1 to 0.2 ppm for *Myriophyllum* spp.; 2,4-D at 2 to 4 kg/ha for waterhyacinth and 20-30 kg/ha for *Nelumbo* sp.; diquat 0.5 to 1 kg/ha for waterhyacinth, 1 to 2 kg/ha for water fern, 0.25 to 1 ppm for hydrilla; terbutryn at 1 to 2 kg/ha for waterhyacinth, water fern and water lettuce. Synergistic interaction of 2,4-D with other herbicides have been observed by Wydianto *et al.* (1977). Their combinations include 2,4-D + glyphosate at 2 + 1 kg/ha; 2.4-D + hexazinone at 2 + 3 kg/ha; 2.4-D + paraquat at 2 + 0.5 kg/ha; 2.4-D + perfluidone at 2 + 1 kg/ha and 2.4-D + terbutryn at 2 + 1 kg/ha.

Giant mimosa has a high regenerative potential, therefore, after becoming established it is very difficult to control. Chemical control is recommended to get an efficient result, however, there are many points which should be considered i.e. different characteristics of the plant, method of application, land use situation, target weed growing, the age structure of weed population and extent of infestation (Miller *et al.*, 1982). In the past giant mimosa was usually controlled by fosamine, silvex + 2.4-D, glyphosate, 2,4,5-T + 2.4-D, picloram/2.4-D (1:4), triclopyr and dicamba (Suwunamek, 1982). 2,4,5-T presently is publicly disapproved due its harmful effects to nontarget organism. Herbicides which have been reported to control giant mimosa are: glyphosate at the rate of 3.0 to 6.0 kg/ha; 2.4-D + silvex at 2.25 + 2.25 kg/ha. Davis and Simagrai (1979) considered that fosamine had very low degree of hazard to the environment, and further reported that fosamine at the rate of 0.31 to 0.52% + 0.25% (100% basis) nonionic surfactant can give complete kill of giant mimosa. Defoliation appears at two weeks after application and dieback symptoms after 4 weeks. Treatment by fosamine can get optimum results in high temperatures and humidity, high soil moisture and good spray coverage. Giant mimosa which has infested rivers and lakes is very difficult to control. The only possibility is by aerial spraying. Kittipong (1982) reported that glyphosate at the rate of 6.0 and 12 kg/ha in 125-375 1 water/ha by aerial spraying gave the best control. The work in Australia reported several herbicides which are promising for controlling giant mimosa such as dicamba, ethidimuron, fosamine, glyphosate, hexazinone, and triclopyr.

BIOLOGICAL CONTROL

Biological control of aquatic weeds has not received much attention from Southeast Asian investigators. However there have been some research works in biological control using insects, fungi and fish to control several aquatic weeds such as waterhyacinth, hydrilla, water lettuce and water fern.

After some period of studies, no promising natural enemies of waterhyacinth could be found in Indonesia. Mottle waterhyacinth weevil (*Neochetina eichhorniae*) was introduced from Florida to Indonesia in 1975 (Kasno & Soeprapto, 1978). Release test was made to study its establishment and role under the field conditions of Cibinong fish pond near Jakarta. The weevil has established in the field butit had a low potential in suppressing waterhyacinth growth (Kasno *et al.*, 1979). The combination of waterhyacinth weevil with spores of *Myrothecium roridum* caused a better suppression of waterhyacinth growth under laboratory conditions (Kasno & Saraswati, 1979). Low dose of dalapon combined with the spores of the fungus showed also a better control under laboratory conditions (Hadi & Saraswati, 1976).

In Thailand in 1977 waterhyacinth weevil was also introduced from Florida and the weevil was released in field. Further, the weevil was introduced from Thailand to Burma as well as to Sri Lanka (Napompeth, 1983).

Research project in biological control of waterhyacinth in Malaysia still use indigenous natural enemies (Caunter, 1983). Efforts tostudy the role of *Paraphynx* sp. (formerly, it was identified as *Nymphula diminutalis* Wlk.) to control Hydrilla were made in Malaysia (Singh, 1974) and Indonesia (Kasno *et al.*, 1979). Herbivorous fish such as grasscarp (*Ctenopharyngodon idella* Val, *Tillapia mossambica* etc.) were evaluated for biological control in Indonesia (Pheang, 1975; Kasno *et al.*, 1979).

Research works for controlling water lettuce were done in Thailand (Suasa-ard and Napompeth, 1976), Indonesia (mangoendihardjo & Nasroh, 1976) and Malaysia (Kasno, 1982). *Episammia pectinicornis* (formerly, it was identified as *Namangana pectinicornis*) and *Proxenus hennia* were proved to be specific feeding insect and promising agent to control water lettuce. *N. responsalis* is one of the insects attacking water fern in Indonesia and Malaysia, however, it is not a specific natural enemy (Kasno, 1982). Other research work on biological control of giant mimosa has being conducted in Thailand with some progress (Napompeth, personal communication).

Table 1 lists the promising biological control agents for some aquatic weeds.

Table 1. Biological Agents which can be used for aquatic weed control in Southeast Asia.

Aquatic weed species		Agents	Remarks	References
Waterhyacinth	Insect	*Atractomorpha crenulata* (F.)	—	Napompeth, 1983
		Gesonula punctifrons Stal.	—	Mangoendihardjo Napompeth, 1983.
		Oxya minima Carl	—	Napompeth, 1983
		Neochetina eichhorniae Warner	Better combined with spores of *Myrothecium roridum.*	Kasno *et al*, 1979 Kasno & Saraswati, 1979.
	Fungi	*Alternaria eichhorniae* Nag Ray & Ponappa	specific to waterhyacinth	Napompeth, 1983 Mangoendihardjo *et al* 1977.
		Myrothecium roridum Tode ex Fr.	Better to combine with low dose of herbicide	Hadi & Setiawati, 1976.
		Rhizoctonia solani Kuehn	—	Napompeth, 1983.
	Fish	*Ctenopharyngodon idella* Val.	Retard the growth of waterhyacinth by eating the root	Pheang, 1975 Kasno *et al*, 1979
Water lettuce	Insect	*Samea multiplicalis* *Guenee*	—	Mangoendihardjo, *1983*
		Paulinia acuminata De Geer	—	Mangoendihardjo, 1983
		Episammia pentinicornis	promising	Mangoendihardjo, 1983 Suasavard &

Table 1. Continued

				Napompeth, 1976 Mangoendihardjo & Nasroh, 1975. Kasno, 1982.
		Proxenus hennia Swinhoe	promising	Mangoendihardjo & Nasroh, 1975 Kasno, 1982.
Water fern	Insect	*Nymphula responsalis* Wlk. —		Kasno, 1983; Mangoendihardjo *et al*, 1977.
Hydrilla	Fish	*Ctenopharyngodon idella*	—	Pheang, 1975
	Insect	*Mymphula diminutalis*		Singh, 1974.

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NEW APPROACHES IN BIOLOGICAL CONTROL OF WEEDS

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CLASSICAL BIOLOGICAL CONTROL

Classical biological control or weeds involves the introduction into a country of insects of other organisms not already present, with the aim that these insects will establish and control the weed. Typically, the target weed is an introduced non-native plant, and the controlling organisms are brought in from the country of origin of the weed.

This classical type of biocontrol has in the past been used very successfully in the Asian-Pacific area, and there are several biocontrol programmes currently in progress which fit this pattern. For example, there is the successful control of black sage *Cordia macrostachya* in Mairitius and Malaysia, by two insects imported from Trinidad in the West Indies . In Australia there are numerous recent examples, the successful control of harrisia cactus *Eriocereus martinii* by the mealybug *Hypogeococcus festerianus*, both from South America, the control of skeleton weed *Chondrilla juncea* by two insects and a rust disease, all from the weed's original home in southern Europe, and the control of alligator weed *Alternanthera philoxeroides* by two insects also originating in South America.

Other projects still in progress include the control of water hyacinth *Eichornia crassipes* and salvinia *Salvinia molesta* in various countries in the region, using insects from South America, and in Australia programmes for the control of a wide variety of plants largely of American origin. My organization the Alan Fletcher Research Station of the Queensland Department of Lands, recently opened a field station in Texas in order to discover, investigate, and introduce into Queensland insects for the control of a number of weeds of north American origin.

NEW APPROACHES: PATHOGENS

Traditional methods of biocontrol, therefore, are not in any way outdated or superseded. There are however a number of new approaches which are being increasingly adopted, of which perhaps the most important is the use of pathogens. Early biocontrol workers were for the most part entomologists dealing with crop pests, who moved from this onto biocontrol of weeds, and this pattern, of employing entomologists who then only consider insects, has tended to perpetuate itself. From the earliest days the damage caused by pathogens has been observed and their utilisation suggested (Johnston and Tryon 1914), but lack of expertise in plant diseases has generally prevented any further action. In addition, because the understanding of plant diseases has in general lagged behind that of insect pests, there has been a lack of good data on the host specificity of the various plant pathogens, and a consequent reluctance on the part of quarantine authorities to authorise their introduction.

This is however slowly being overcome. The rust *Puccinia xanthii* was accidentally introduced into Queensland on noogoora burr *Xanthium strumarium*, after the deliberate introduction was prohibited on the grounds that sunflower *Helianthus annuus* might be attacked. In the event, the rust spread rapidly and has resulted in good control of the burr in most areas, with no damage at all to sunflower crops. Since then, the rust *Puccinia chondrillae* was successfully introduced into southern Australia where it is a major factor in the control of skeleton weed. The Department of Lands in Victoria has been investigating the use of a rust to control wild blackberry *Rubus*, but possible damage to both native *Rubus* spp. and to cultivated blackberries has prevented any introduction so far. My organization is currently considering two rusts from North America for the control of parthenium weed *Parthenium hysterophorus* and although considerable and detailed host-testing will be required, we do not anticipate major problems.

Another new approach being increasingly investigated particularily in the USA is the use of native plant pathogens as mycoherbicides. This entails the production of spore material in a concentrated form suitable for use as a spray or dust, which is then applied to the weed in the same way as any other herbicde. The technique has the advantage of being selective, thus the spray can be used even in growing crops, and is acceptable in situations where use of chemical herbicides would cause public reaction. Mycoherbicides can also be used where disagreement over the value of a plant prevents classical biocontrol *i.e.* the introduction of new organisms. However the disadvantages are great, for the cost both of preparation and application is high, the control only lasts one season so that re-application is necessary each year, and usually only one weed or group of weeds will be controlled.

NATIVE INSECTS AND NATIVE WEEDS

Another 'new' approach which in my view is impracticable, is the attempt to manipulate native insects to obtain control of an introduced or native weed. This has been suggested in a number of instances, both in the Asian-Pacific region and in South America. The chief attractive feature is that expensive overseas programmes and quarantine facilities become unnecessary. However the principle is unsound, as any local insects capable of causing controlling damage to a weed will do so without human interference. A failure is the result of some restraining factor in the environment, usually biotic, and successful control would require that this be identified and removed, which will generally be impossible. Regular releases of laboratory-reared insects on a large scale is prohibitively expensive, and could not possibly be cost-effective for weed control. Nevertheless, even where overseas programmes are impracticable, successful biocontrol can still be achieved with weeds where the preliminary work has been undertaken by another country. Thus black sage in Malaysia was controlled using insects which had already been introduced into Mauritius for the control of the same weed. Control agents against water hyacinth and salvinia have been extensively investigated by the USDA, the CIBC in Trinidad, and the CSIRO in Australia. Asian-Pacific countries can benefit from this, obtaining suitable insects from any of these organisations and introducing them after whatever quarantine trials are considered necessary. Several other weeds of the region have similarily been the subject of biocontrol programmes somewhere in the world, eg *Chromolaena (Eupatorium) odorata*, *Parthenium hysterophorus*, *Mimosa pigra* and *M. invisa*, *Solanum elaeaginifolium*.

Another new approach is the use of biocontrol against native weeds. This is not truly 'new' as there have been several examples of successful control of native weeds by introduced organisms, *e.g.* of *Tribulus* spp. and *Opuntia* spp. in the West Indies, but despite this, biocontrol is still often promoted only for introduced weeds. Wherever a native weed belongs to a widespread genus, with representatives occurring naturally in other parts of the world, there is a good chance of finding suitable organisms for its biocontrol. Currently the USDA are investigating the biocontrol of weeds in the native genera *Proposis* and *Baccharis* (DeLoach 1980) and both the USA and Canada have been working on weeds in the genus *Ambrosia* for some time. World-wide weeds such as nutgrass *Cyperus* spp. and bracken *Pteridium* would seem obvious candidates for this kind of biocontrol. Indeed some introductions have already been attempted on *Cyperus*, but on bracken although various potentially useful insects have been recorded (Kirk 1977), to my knowledge no introductions have yet been made.

THE FUTURE

What then is the future of biocontrol of weeds, and where should it be moving? Firstly, a great deal more money and effort needs to be put into biocontrol. There are still very few countries, both in the Asian-Pacific region and world-wide, with any sizeable input at all. My organisation, with 7 graduate scientists employed permanently on biocontrol of weeds, is one of the largest in the region, while a veritable army of scientists is employed on the various aspects of chemical weed control. Yet as already discussed the biocontrol of many important weeds in the area could be attempted with a minimum of expense, and with very great benefits if successful. Nor does the failure of biological control of a weed in one area mean that further work is useless. Each country represents a different ecosystem, and biocontrol agents which have failed in one country may succeed in another. Examples are the relatively greater success of *Procecidochares utilis* against *Ageratina (Eupatorium) adenophora* in Hawaii than in Australia, and the variable success of *Chrysolina* spp. against *Hypericum perforatum* in different countries of the world. Consequently all suitable agents should be tried, even if results in other countries have been poor.

Secondly, crop weeds should be considered for biocontrol. There is still a tendency to assume that weeds of crops are not suitable subjects for biocontrol, despite the success with skeleton weed in wheat in Australia. Wherever the principle problem in a crop is a single weed species, biocontrol should be considered. It is only when a complex of species are of equal importance that biocontrol is probably unsuitable.

Finally, I would like to direct attention to the problem of graminaceous weeds. Traditionally, biocontrol has never been considered for these, as it is felt the threat to grain and grass crops is too great. Yet many biocontrol agents are extremely specific, not only to the plant species but even to the race or strain. Many of the insects introduced for the control of *Lantana camara* are effective against only some of the varieties (Smith and Smith 1982). All three organisms established against skeleton weed proved to be selective in their attack on the three forms of the weed present in Australia, and new strains of the rust are currently being sought against the two forms of the weed not yet adequately controlled (Hasan 1980). It should therefore be possible to find highly-specific organisms which will attack at least some of the graminaceous weeds without any risk to related crops. The search must however be made in the country of origin of the weed, and on the exact strain or sub-species which has become a weed, and to establish this might sometimes require considerable initial work. However, out of 18 weeds listed as the world's worst, 10 are graminaceous (Holm et al 1977), so the return from successful biocontrol would justify even an enormous initial outlay.

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ALLELOPATHY AND WEED MANAGEMENT IN CROPPING SYSTEMS

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ABSTRACT

Allelopathy, based upon secondary phytochemicals, is a component of the interference which occurs between living plants. In contemporary cropping systems weeds employ allelopathy more effectively than do crop plants but the allelopathic potential of crops might be enhanced as a means to combating interference by weeds.

Phytochemicals are also produced during senescence and decay of plant material. The management of such chemicals in cropping systems is discussed, with special reference to stubble retention systems.

INTRODUCTION

Reports of chemical interactions between plants date from at least the early 17th Century (Lee and Monsi, 1963), receiving periodic boosts from the work of pioneers such as de Candolle (1832) who discussed "soil sickness" in the context of plant exudates, and Bedford and Pickering (1919) who report on the "baleful" toxic influences of one plant upon another. Within the past decade, considerable interest has developed in allelopathy as a component of the "interference" (Harper, 1977) which takes place between plants.

Molisch (1937) recognized the significance of allelopathy and broadened its literal meaning, "mutual harm", to encompass the range of biochemical interactions which take place between plants of all levels of complexity. It is now appreciated that such interactions may be positive (stimulatory) or negative (inhibitory) and that this appears to be a consequence of the concentration of chemicals involved (Lovett, 1982a).

The chemicals involved in allelopathy are termed "secondary compounds" since they are produced as by-products of primary metabolic processes (Levin, 1976). They are, chemically, very diverse (Schildknecht, 1981). So far as is known, all plants possess these compounds and whilst some are identified particularly with certain families of plants, for example, the glucosinolates with the Brassicaceae (Kjaer, 1976), others are more cosmopolitan.

Allelochemicals may occur in all parts of plants, a recent report indicating that even the pollen of *Parthenium hysteropherus* L. (Kanchan and Jayachandra, 1980) has allelopathic properties. However, allelochemicals are more commonly concentrated in the leaves and roots.

The release of allelochemicals to the environment and their ultimate destination depends heavily upon water. Water is also essential to the transfer of allelochemicals from plant to plant, from plant to soil and within the soil (Winter, 1961).

As indicated, above, the concentration of allelochemicals is critical to their effect. Frequently, in washings of live plant material, the concentration of allelochemicals is small and may stimulate the growth of test species (Lovett, 1982a). Many of the chemicals, however, accumulate in the soil to attain toxic concentrations (Muller, 1966) or may be accumulated within the producing plant to be released in relatively high concentrations when the necessary pre-disposing conditions occur (Lovett, 1982a).

Winter (1961) drew attention to the fact that the readily observable manifestations of damage caused by plant-drived chemicals, such as impaired germination or reduced root or radicle extension, are secondary expressions of primary disruptions to metabolic processes of the types subsequently noted by Rice (1979). Recent developments in analytical techniques and in fields such as electron microscopy, which enable primary effects to be more accurately identified, have validated the conclusions of Winter made more than twenty years ago.

A major factor in promoting interest in allelopathy has been the recogntion, in recent times, that the relatively subtle modes of action which are being sought in modern generations of herbicides (Moreland, 1980) are allied to the modes of action which have been defined for allelochemicals by Rice (1979) and other workers.

The action of secondary chemical compounds represents only a part of the complex interactions which take place between plants and other organisms and which are constantly modified by prevailing soil and climatic conditions. In these circumstances, it is understandable that only the most dramatic examples of allelopathy may be readily recognized (Whittaker, 1970). It may, however, be widespread but less obvious allelopathic manifestations which are of the greatest significance, overall, to associations of crops and weeds.

ALLELOPATHY IN CROPPING SYSTEMS

Where allelopathy has been investigated in the context of cropping systems, the overwhelming evidence is for weeds to use allelopathy as a part of their interference with crops. However, crop-on-crop, crop-on-weed and weed-on-weed examples of allelopathy are known (Klein and Miller, 1980).

Allelopathy is usually associated with interactions between living plants and, in this paper, reference will be made primarily to experiments in which whole plants, rather than macerated fractions, have been employed. The adoption of cropping technologies in which plant residues are maintained on soil surfaces or are lightly incorporated into surface soil has led, however, to a recognition that chemicals released during senescence and decay may also affect crop with weed relationships and examples of work in this area will be included.

Allelopathic effects of weeds on crops

This topic is extensively documented in the reviews of Rice (1974, 1979). Most workers report secondary manifestations of allelochemicals, of the types previously noted, whilst there is a small number of investigations in which the primary effects also have been detailed (for example, Koch and Wilson, 1977; Protic, Andelic and Vasiljevic, Lj., 1980).

Given the complexities of systems in which allelochemicals operate, it is understandable that few attempts have been made to discriminate between the effects of allelopathy and other components of interference. One such example is cited in the Annual Report of the International Institute of Tropical Agriculture (1981) where the effects of weeds upon the final yield of yam (*Dioscorea rotundata* Poir.) were partitioned, as shown in Table 1. The authors were not explicit as to the components of interference other than allelopathy but it may be inferred that "full interference" encompassed factors below ground which severely affected tuber yield. Over the three years of the experiment, average losses of 30.3% were attributable to allelopathy whilst average losses of 8.5% and 38.0% were attributable to other factors of interference above and below ground, respectively. The difficulties of quantifying the effects of allelopathy are exemplified by these data. The problem is an intractable one which has militated against a wider recogntion of allelopathy as an important component of plant interactions in cropping systems.

One of several associations of weeds with crops currently under investigation by our research group is that of *Datura stramonium* L. (thorn-apple) with *Helianthus annuus* L. (sunflower). Thorn-apple is reported as competing with summer crops for moisture, light and nutrients (Felton, 1979). In addition, all parts of the plant, but in particular the seeds, contain tropane alkaloids which show allelopathic activity in various sterile media and in soil

(Lovett, Levitt, Duffield and Smith, 1981; Lovett and Levitt, 1981). Data which typify the effect of washings of thorn-apple seeds upon radicle elongation in sunflower are presented in Table 2. These data indicate that a similar degree of inhibition of radicle elongation is achieved with a solution of scopolamine, onf of two alkaloids identified in the seed washings.

Table 1. Mean fresh tuber yield and yield losses of white yam (Dioscorea rotundata) *grown in boxes as affected by mode of weed interference (1978-80).*

MODE OF WEED INTERFERENCE	FRESH TUBER YIELD (kg/box)			YIELD LOSS (%)		
	1978	1979	1980	1978	1979	1980
Interference by aerial factors	1.83 ab	0.72 ab	2.48 a	16.44	20.88	+11.70
Interference by aerial factors and allelopathy	1.26 bc	0.58 b	1.38 b	42.47	36.26	37.80
Full interference	0.53 c	0.22 c	0.47 c	75.80	75.82	78.80
Weed-free control	2.19 ab	0.91 a	2.22 a	0	0	0

Means identified by the same letter in the same column are not significantly different at the 5% level, Duncan's New Multiple Range Test.

(Modified from I.I.T.A., 1981).

As indicated by Whittaker and Feeny (1971) all allelochemicals ultimately reach the soil, where they may have direct or indirect effects on plant growth (Lovett, 1982a). Thus, the fate of the alkaloids of thorn-apple in the soil is of importance in assessing its allelopathic potential in cropping systems. As in experiments with other species (for example, Lovett and Lynch, 1979), soil type is critical to the degree of inhibition achieved with a given allelochemical. In the case of thorn-apple, greater inhibition was achieved in a lateritic podsolic soil as compared with a black earth (Levitt, unpublished data). Observations by Winter (1961) suggested that plants take alkaloids from the soil by processes similar to those involved in nutrient uptake. Thus, soil factors which influence plant nutrient uptake, such as particle size, clay and organic matter contents, may also influence the uptake of alkaloids.

The alkaloids contained in thorn-apple seeds must be leached from those seeds before germination can take place. However, once leached from the seeds, the alkaloids retard the germination of other species in the vicinity. In a field experiment of 35 weeks' duration (Levitt, unpublished data), thorn-apple seeds placed in the soil under ambient conditions remained significantly toxic to germinating sunflower seedlings for the first 15 weeks of the experiment. The duration of this inhibitory effect might be expected to vary with climatic conditions. The problem may be aggravated in irrigated cropping, where thorn-apple is particularly serious (Felton, 1979).

Table 2. Effect of Datura stramonium *seeds, leachate and a 0.5% scopolamine solution on* Helianthus annuus *radicle elongation in two media. (Means of five replicates each of 20 seeds.)*

	H. annuus radicle length after 72 h incubation at 24°C				
Medium	50 ml sterile water	50 ml sterile water + 550 *D. stramonium* seeds in soil	50 ml 0.5% scopolamine solution	50 ml leachate (from 5500 *D. stramonium* seeds)	P
Sterile coarse sand	50.3 a	34.6 b	29.4 bc	25.9 c	0.001
Sterile 4:1 soil + peat	53.2 g	40.6 h	38.8 h	15.1 i	0.001

Means identified by the same letter in the same row are not significantly different at the 5% level, Studentized Range Test.

(After Lovett and Levitt, 1981.)

In the case of thorn-apple, it has been possible to identify the allelochemicals present and to obtain some indication of the concentrations at which they adversely affect crop species. The observations reported in Table 2 are typical of the type of secondary manifestations associated with allelopathic activity. Recent transmission electron microscopy has shown that these secondary effects stem from primary interference with the utilization of energy substrate by the seedling during the initial phases of growth (Levitt, unpublished data).

Allelopathic effects of crops on weeds

Whilst the number of reports of allelopathy as a significant component of interference with weeds by crops is small, there are some well-documented examples. Putnam and Duke (1974) reported that within cucumber (*Cucumis sativus* L.) there were some un-selected accessions which were capable ofseverely inhibiting weeds, representing important broad-leaved and narrow-leaved genera, under controlled conditions. The authors considered that, if the factor responsible was heritable, attempts could be made to incorporate it into a commercial cultivar. Lockerman and Putnam (1979) carried out further evaluations of cucumber under field conditions, concuding that allelopathic manifestations could be expected under specific environmental conditions. They indicated that investigations of the effect of moisture levels and soil type interactions were required. In subsequent studies, Lockerman and Putnam (1981a, b) confirmed that the hybrid cultivar "Pioneer" was less well-equipped for chemically-based interference than a wild accession to which it had previously been compared.

In work with 3,000 accession of *Avena* spp. (Fay and Duke, 1977), all showed evidence of the presence of the allelochemical scopoletin. 25 acessions of *Avena sativa* L. (common oat) were chosen for study. The accession PI 266281, when compared with cv. Garry, exuded more scopoletin on a weekly basis (Figure 1). However, whilst both PI 266281 and Garry interfered with the growth of mustard in a soil system (Figure 2) there was no correlation with their relative levels of scopoletin. Fay and Duke (1977) considered that allelochemicals were possibly being adsorbed by soil particles or metabolized by soil micro-organisms and that the phytotoxic effects observed were probably the result of snyergism between scopoletin and other allelochemicals.

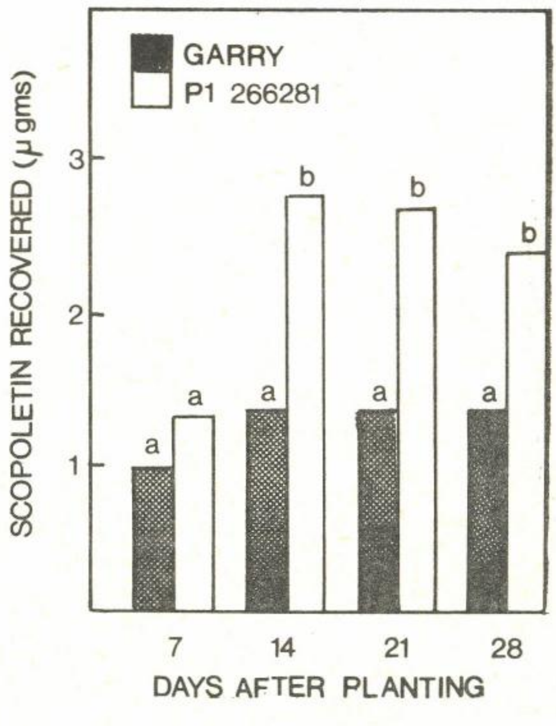

Figure 1. Interference of "Garry" and PI 266281 oats with wild mustard in sand culture and the amount of scopeletin recovered per pot. Bars with the same letter do not differ at 5% level of significance. (After Fay and Duke, 1977.)

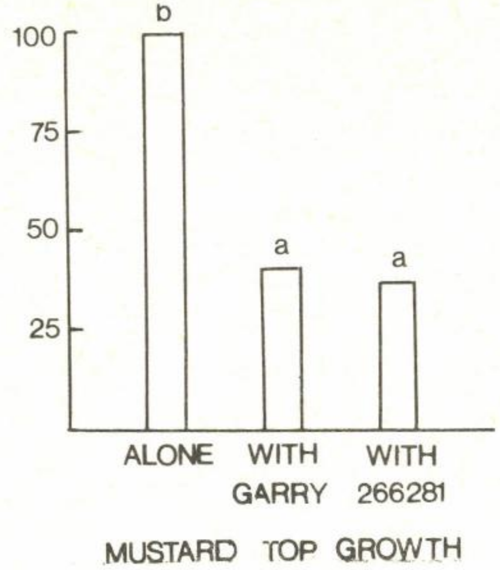

Figure 2. Interference of "Garry" and PI 266281 oats with wild mustard in a soil system. Bars with the same letter do not differ at the 5% level of significance. (After Fay and Duke, 1977.)

Rice (1974) reviewed work in which wild sunflowers (*Helianthus annuus* L.) in the United States demonstrated allelopathic activity as part of an invasive capacity in the field. Although Leather (1983) claims that cultivated sunflowers are allelopathic to weeds, his experiments were based on dried and milled material. 13 cultivars were tested of which 3 hybrids tended to be more consistently inhibitory than other cultivars. Germination responses of 17 weed species, including *Chenopodium album* L., *Datura stramonium* L. and *Sorghum halepense* (L.) Pers., some of the worst weeds in the World (Holm, Plucknett, Pancho and Herberger, 1977), showed mixed responses in germination and seedling growth to allelochemicals. Lovett, Fraser and Duffield (1982) found little evidence for allelopathic activity by naturalized populations of sunflower in Australia or by cultivars other than a single, unreleased hybrid. This work was based on washings of foliage of entire sunflower plants. That a possibility for selection for enhanced allelochemical activity by sunflower exists was, however, indicated by the finding that one inbred parent of the hybrid possessed similar allelochemicals and evoked responses similar to those of the hybrid (Table 3).

In these examples, cultivars exhibited lower levels of allelopathic potential than did less selected examples of the same species. This accords with the view that selection which has been applied to crop species has tended to diminish the phytochemical content to the detriment of self-defense mechanisms, including allelopathy as a means to interfere with weeds (Lovett, 1982a). This hypothesis is strengthened by the findings of Massantini, Caporali and Zellini (1977) that, of 141 lines of soybean (*Glycine max* L.), only two exhibited severe inhibition of the broad-leaved weed *Helmintia echioides* (L.) Gaertn. and none were significantly effective in reducing the growth of the grass weed *Alopecurus myosuroides* Huds.

Table 3. Effect of washings of green sunflower foliage on coleoptile height and length of longest seminal root of wheat after 120 incubation at 24^{o}C. (Means of five replicates of 20 seeds.)

	Distilled water control	Foliage washings Hybrid	Foliage washings Inbred parent	P
Coleoptile height (mm)	47.0 a	41.0 b	40.0 b	0.001
Longest seminal root (mm)	68.3 a	61.2 b	59.8 b	0.001

Means identified by the same letter in the same row are not significantly different at the 5% level, Studentized Range Test.

(After Lovett, Fraser and Duffield, 1982).

Barley (*Hordeum vulgare* L.) is commonly used as a "smother" crop to suppress the growth of weeds, its effectiveness in this capacity having been attributed to competition for environmental resources (Overland, 1966). However, in the absence of such competition, barley still inhibits germination and growth of some weed species. Overland (1966) established that the inhibitory activity was selective amongst broad-leaved plants, chickweed (*Stellaria media* (L.) Cyr.) being more severely inhibited than Shepherd's Purse (*Capsella bursa-pastoris* (L.) Medic. Bell (1970) indicated that *Brassica nigra* (L.) W. Koch, a dicotyledonous component of annual grasslands in southern California, was notably allelopathic to the annual weed grasses *Avena fatua* L., *Bromus rigidus* Roth and *Bromus mollis* L. present in thse flora. *B. nigra* has long been cultivated in Europe for its seed and it is of interest that the related species white mustard (*Sinapis alba* L.) was reported by Putnam and Duke (1978) to be employed in the Soviet Union as a companion crop which, presumably by conferring a defensive capability, enhanced the yield of several crops with which it was grown.

Although some suggestions as to the possible toxic components present in preparations from cucumber plant fractions are made by Lockerman and Putnam (1981b), positive identification of the chemical or chemicals concerned has yet to be made. Extracts from leaves, roots, fruit and seeds produced allelopathic effects although Lockerman and Putnam (1981b) considered that the mechanisms of toxicity differed between plant·and seed fractions.

As noted, scopoletin was recovered from oat seeds (Fay and Duke, 1977) and from root exudates. Phenolic compounds,

As noted, scopoletin was recovered from oat seeds (Fay and Duke, 1977) and from root exudates. Phenolic compounds, cosmopolitan in higher plants (Levin, 1976), have been identified as allelochemicals of sunflower (Fraser, 1983; Leather, 1983). Reference is made by Rice (1974) to exudation of allelochemicals by sunflower in the field and, in the work of Lovett, Fraser and Duffield (1982), such chemicals were present in aquaeous leachates of intact foliage. In common with experiments which we have conducted on other species, decaying and dried residues of similar sunflower material proved to have a higher allelopathic activity, a finding which correlates with those of Leather (1983). In experiments with barley, however, Overland (1966) determined that leachates of living roots were more inhibitory than were leachates of dead ones. On this basis, she argues for an active metabolic secretion of allelopathic substances, in this case alkaloids. Aqueous leachates of seeds of barley also caused inhibition of germination and growth.

Hydrolyzsed extracts of *Brassica nigra* and *Sinapis alba* both contain aglucones (Coles, 1976) chemicals which are characteristic of the Brassicaceae. The method by which endogenous chemicals of the Brassicaceae are released to the environment, where they may have allelopathic activity, is not well defined although Bell (1970) states that "A potentially highly allelopathic volatile toxin from living vegetative parts of *Brassica "(nigra)"* was shown to lack an ecologically effective mechanism." In the case of the weed *Camelina sativa* L. Crantz, the release of an allelochemical has been associated with the activity of bacteria in the phyllosphere (Lovett and Duffield, 1981), a sophisticated association which may indicate how the "allelopathic volatile" noted by Bell (1970) was liberated to the environment.

The examples which have been cited indicate a range of sources and types of allelochemical from crop plants which may be involved in allelopathy with weeds. It is possible that some may be harvestable and could be exploited as natural herbicides or growth regulators. In this context, it is of interest that experiments with buckwheat (*Fagopyrum* spp.) (Tsuzuki, Katsuki, Shida and Nagatomo, 1977; Tsuzuki, 1981) indicated that aqueous extracts inhibited germination of crops and weeds, including *Cyperus rotundus* L. Abscisic acid, already widely employed in agriculture as a plant growth regulator (Nickell, 1982), was identified as a possible allelochemical in these experiments.

Phytochemical effects of crop residues on weeds

In the work of Bell (1970), previously discussed, potential allelochemicals were produced during life and water-soluble toxins were produced from standing dead stalks and leaf material remaining in soil. Interest in the phytochemicals produced during decay of crop residues has been enhanced by the increasing usage of techniques such as stubble retention and minimal tillage (Lovett and Jessop, 1982). The chemicals involved may be washed directly from crop residues or may result from microbial activity during decomposition (Lynch and Cannell, 1980). The degree to which soil conditions are aerobic or anaerobic affects the types of micro-organism present, the rates of their activity and the ultimate nature of thechemicals produced (Lovett, Hoult, Jessop and Purvis, 1982).

Whilst most workers have concentrated on the effects of phytochemicals producing during decay of crop residues on the growth of subsequent crops, there are a few reports of the growth of weeds also being affected. Cold, aqueous extracts of wheat straw differentially affected germination, and sometimes growth, of the broad-leaved species *Ipomoea hederacea* Jacq., *Abutilon theophrasti* Medik., *Sida spinosa* L. and *Sesbani exaltata* Rydb. but the annual grass weed *Echinochloa crus-galli* (L.) Beauv. was unaffected (Steinsiek, Oliver and Collins, 1980). DeFrank and Putnam (1977) studied several crops, including *Sorghum bicolor* (L.) Moench and *Sorghum sudanense* (Piper) Stapf. Populations of the common weed species *Portulaca oleracea* L. and *Digitaria ischaemum* (Schreb.) Muhl. were influenced both by living crop plants and their residues. Both crops reduced the population of *D. ischaemum* by almost 100% whilst reducing *P. oleracea* populations by some 50%. Additional data (Putnam and DeFrank, 1979) are discussed in the context of the use of allelopathic cover crops to inhibit weeds. It was concluded that "certain plant residues can contribute exceptional weed control". Thus, there is the possibility that control of weeds may be added to the other advantages inherent in stubble retention practices (Lovett *et al.*, 1982).

Our own work confirms indications that crop residues in rotational systems may exhibit selective toxicity towards certain weeds or groups of weeds. Residues oc S. bicolor, for example, which show a high degree of toxicity towards germinating wheat seedlings, toxified the annual grass weeds, *E. crus-galli* and *E. colonum* (L.) Link, to a much greater extent than annual broad-leaved weed species, Table 4. Froud-Williams, Chancellor and Drennan (1981), in their review of likely changes in weed floras as a consequence pf tje adoption of reduced-cultivation systems, suggest that annual and perennial grass weeds are likely to increase in importance. Given that phytotoxic selectivity occurs between crop residues, the possibility of utilizing crops in rotation to sequentially overcome problem weeds might be considered.

There are also examples in the literature of phytotoxic effects of weed residues upon crops Bhowmik and Doll (1980) report on a field study in which residues of *Chenopodium album* L., *Amaranthus retroflexus* L., *E. crus-galli* and *Setaria faberi* Herrm. reduced crop growth in spring after being cut in autumn and exposed on the soil surface over winter. As in the previous example, there was evidence of selectivity in the extent to which specific weeds affected the growth of specific crops.

Table 4. Effect of sorghum residue on growth of annual weeds (46 days after application of residues at 5 t/ha). (Means of four replicates.)

	Echinochloa crus-galli and *E. colonum*		*Hibiscus trionum*	
	Number per m^2	Dry weight g m^2	Number per m^2	Dry weight g m^2
No residue	3046	227	244	2.3
Sorghum residue	1216	116	186	1.9
% reduction	60	49	24	17
LSD (t) 1%	1000.7	99.5	N.S.	N.S.

Herbicide application is an essential component of some reduced tillage techniques. Lynch and Penn (1980) cite several factors which could be involved in the damage which has been noted in cereals following the use of herbicides such as glyphosate in this mode. These include uptake of residual herbicide From the soil or from decomposing plant remains; production of phytotoxins from such remains and infection of the crop by pathogenic micro-organisms colonizing weed residues. In experiments where rhizomes of couch grass (*Agropyron repens* (L.) Beauv. were killed by the application of glyphosate, plant death of barley (*Hordeum vulgare* cv. Proctor) was attributable to a combination of pathogenic and toxic effects. The toxins were identified as acetic and butyric acid, which are commonly produced under conditions of anaerobic decay. Acetic acid has been identified as the principal toxin produced from residues of cereal crops, although butyric acid may be more toxic (Lynch, 1977). In later work (Lynch, Penn and Gussin, 1981), it was concluded that problems arising from the decay of couch grass rhizomes are mainly due to the presence of pathogens (*Fusaria* spp.) but that the cereal host may be predisposed to infection by organic acids produced during decay of the couch rhizomes.

Residues of *A. repens* may not produce concentrations of acetic acid as high as those commonly associated with anaerobically decomposing residues of cereal straws (Lynch, 1978). However, given that perennial grass weeds undergo almost continual loss and renewal of organs of vegetative reproduction (Hakansson, 1977), the continued presence of phytotoxic quantities of volatile fatty acids must be considered as a potential component of interference. Further, whilst reference here has been made specifically to effects of herbicides in reduced cultivation systems, wherever herbicides are employed or where substantial natural amounts of detritus are present (Wilson, 1981), there will exist the possibility of phytotoxin production from decomposing remains of weeds.

CONCLUSION

Several possibilities for the harnessing of allelopathy as an aid to weed management emerge from this review. Whilst, in contemporary agricultures, weeds appear to be most effective in employing allelopathy as a component of interference, evidence has been presented that the content of allelochemicals in living crops plants might be genetically enhanced in order to defend the species concerned or, perhaps, to extend this defence to a companion crop. Defence against other higher plants may also be effective against other higher plants may also be efffective against other organisms (Lovett, 1982b). After death, crop plant residues also have the potential to inhibit weed growth.

During life and after death the allelochemicals produced by plants exhibit many of the characteristics and modes of action desirable in herbicides (Moreland, 1980). In particular, they are frequently selective; they are effective at low dose rates and, being "natural" products, they lack the adverse residual effects which have been associated with some synthetic chemicals in recent years.

Natural products, for example, the pyrethrins, have long been harvested and used in plant protecton, indeed, the pyrethrins have been so successful that synthetic analogues, the pyrethroids, have been produced and deployed in plant defence (Leahey, 1979). The opportunity may well exist for further products to be utilized in this way but the more attractive opinion is to manipulate allelopathy, as an aid to weed management, by the development of the allelopathic capabilities of crop plants and by the manipulation of their residues in cropping systems.

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CHANGING TILLAGE PRACTICES

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Until this century, cultivating crops for food always included a large input of human and animal power. These sources of energy were clearly exhaustible and, therefore, were husbanded carefully. This is still true in peasant farming today but in farming systems which are developed around powerful machines the physical effort of the farmer and his beasts is no longer a major consideration. This is apparent from the growing volume of literature on soil management — see, for example, Crosson 1982. This comprehensive review of changing cultural practices in North America concludes that over half of the total cropped areas will be managed with some form of reduced tillage system by the eyar 2010.

In modern farming the time-honoured operations of cultivation — harrowing, discing, hoeing, etc — are often combined in one pass of a power-driven implement. Frequent use of such equipment can result in structural deterioration of the soil. Although New Zealand cropping areas have not generally been cultivated to extremes that have resulted in soil erosion the damaging effects of highly mechanised land preparation, to 'force' seedbeds, for example, can eventually build up to the detriment of the soil. Experienced farmers often agree that it is becoming increasingly difficult to create a good tilth.

At Levin Horticultural Research Centre information has been gathered on the long-term effects of soil cultivation on weed populations. In one experiment plots were thoroughly cultivated to 25 cm depth at three-weekly intervals over a period of seven years (see Figure 1, deep cultivation treatment). Weed seedlings were recorded before each cultivation and annual totals are shown. With little replenishment of seed from beyond one trial, numbers gradually declined from an initial viable seed population of more than 230 million per hectare. If about one tenth of the total population germinate each year under normal cultivation frequency, about 8 million per hectare would emerge in a fourth-month growing season. Thus, in a crop of medium density, like sweetcorn, lettuce or beans, every crop plant may be outnumbered by 50 to 100 weed seedlings in an intensively cultivated soil.

Intensive cultivation practices have grown up with the need to maintain control of weeds but nowadays herbicides provide another option. Their value may be enhanced by exploiting timely cultivation to stimulate germination. For example, the 'stale seedbed' technique can be used to encourage a flush of weeds which are then sprayed off with a desiccant herbicide before the crop emerges. Also, selective herbicides can be used effectively when the target weed population has been encouraged to emerge quickly and evenly in the seedbed. Frequent shallow cultivation, with no replenishment, may eventually result in exhaustion of the supply of viable seeds in the surface soil. This would explain the comparatively low counts, little higher than on uncultivated soil.

Preservation of soil structure is usually the major reason for reducing cultivation and the adoption of a suitable technique relies absolutely on effective vegetation management, usually with herbicides. It has been attempted with varying success in many parrts of the world under a variety of titles: "minimum tillage", "zero-till", "direct drilling", "chemical ploughing" and now "conservation tillage". After early work with the herbicide dalapon and then paraquat, attempts to reduce cultivation have received fresh impetus in New Zealand with the recent introduction of glyphosate.

Several horticultural crops have grown well in no-cultivation systems at Levin HRC. Soil conditions have improved, annual weeds have been reduced and earthworms have increased in number. Problems still occur with perennial weeds, certain pests (especially slugs) and fertilizer application techniques. Best results have been obtained with crops of sweetcorn, broadbeans, pumpkins and gherkins (Cox 1977; Cox 1979). When seeking alternatives to conventional tillage there is now enough research experience for a cropping farmer to take exploratory steps to reduce unnecessary cultivation.

Less radical changes in tillage practice can also be considered as a means of overcoming some difficult weed problems. For example, no herbicide will

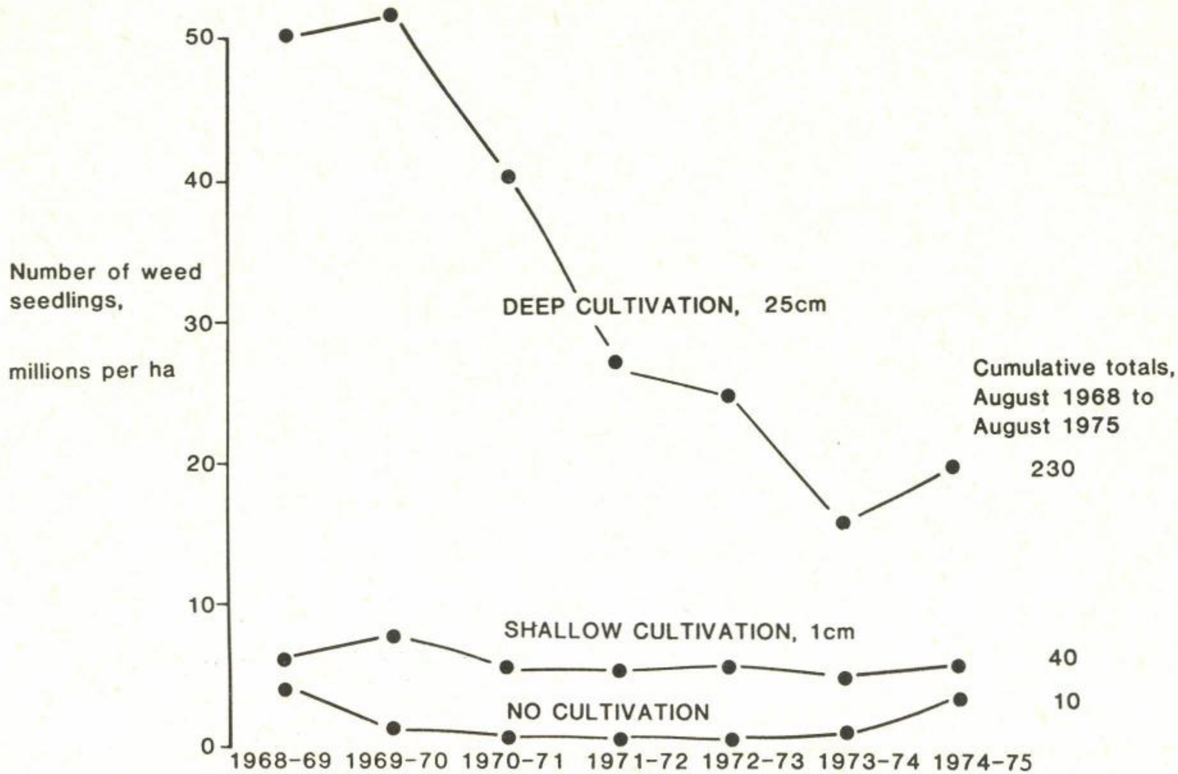

Figure 1. Weed emergence over seven years from plots cultivated and recorded at three-weekly intervals; totals as at mid-August each year.

control solanaceous weeds in direct-sown tomatoes. Normally the seedbed is made just before sowing and the crop and weed seedlings emerge together. Experiments have shown, however, that if tomato beds can be prepared well ahead of sowing, in the winter or even the previous autumn, and the crop sown into the stale seedbed, weed germination is minimised and more easily dealt with in the time available before tomato emergence. The technique can be taken a stage further by sowing a temporary grass or cereal cover on the prepared beds. The cover is then desiccated with a herbicide and the crop sown with a especially designed seed drill. This system provides the soil surface with some protection against wind or rain but takes the land out of production during several months before sowing the crop.

Producing crops to a pre-planned schedule is an aim of efficient food processing operations and most farmers are hindered by uncertainties of the weather. Reduced cultivation systems lessen the delays caused by wet soil conditions at planting time. In wet weather undisturbed soils are firmer than cultivated seedbeds and have a greater capability to carry tractors. It may be possible to sow early peas, for example, in a minimum tillage system when the land would be impossible to work in wet spring weather and so maintain target sowing dates. Similar advantage can be gained at maturity when firm soils may be more capable of carrying heavy harvesting equipment.

There are many reasons for change in cropping systems. Usually the most urgent and obvious ones are simply economic. Ever-rising costs of tractor fuel may be sufficient stimulus for a crop farmer to test a reduced cultivation technique. Whether the motivation comes from immediate operational costs, more predictable sowing and harvesting schedules or longer-term conservation concerns, the modern farmer now has considerable freedom of choice before deciding how much to cultivate his land.

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DISTRIBUTION OF C_3 AND C_4 WEEDS AT THREE DIFFERENT CROP HABITATS OF AN EXPERIMENTAL FARM

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ABSTRACT

Thirty-five weeds present at three different crop habitats of an experimental farm were identified as C_3 and C_4 plants by the CO_2 compensation points, the presence or absence of Warburg effect and/or by Kranz structure in leaf anatomy. The CO_2 compensation points were distinctly divided into two groups: high, greater than 400 ppm; and low, less than 10 ppm. The former always had the Warburg effect and did not have Kranz structure. In the asparagus field where there was no heavy shading, temperatures were higher and soil aridity higher C_4 weeds were apparently abundant. But most of the weeds were perennial C_3 weeds either with prostrate or rosette form in the trellis-trained grapevine, where there were the conditions of heavy shading, cooler temperature and relatively high moisture in soil. In the lowland rice eight out of fourteen weeds were C_3 plants. An attempt was made to relate the C_3 and C_4 distribution to the conditions of the crop habitats.

INTRODUCTION

To explain plant competition on a biochemical basis, Black *et al.* (1969) proposed that among many morphological and physiological factors which affected plant competition, the primary determinant was probably the capacity for CO_2 fixation, and divided various crops and weeds into two groups; efficient and non-efficient plants. Essentially, the former is C_4 and the latter, C_3 plants. They listed possible traits of the efficient plants for the high competitive ability; increased growth and vigor as increase of the light intensity and temperature, no inhibition of growth at the normal oxygen concentration, absence of apparent photorespiration, a high affinity of phosphoenolpyruvate carboxylase for CO_2 and low CO_2 compensation point. In addition, C_4 plants have a lower water requirement than C_3 plants. Hence, it is conceivable that among arable weeds C_4 weeds tend to be dominant in summer crops and highly competitive in particular when the crop is a C_3 plant.

Identification of C_3 and C_4 plants is usually achieved by determining some of the photosynthetic characteristics such as the pathway of $^{14}CO_2$

fixation, leaf anatomy, CO_2 compensation point, and Warburg effect (Downton, 1975; Ishii and Murata, 1978; Krenzer *et al*, 1975; Noda and Eguchi, 1973). Although many plants have been identified in this respect and many reviews were presented (Downton, 1975; Ishii and Murata, 1978; Krenzer *et al*, 1975; Matsunaka and Saka, 1977 b; Matsunaka and Saka, 1977b), information on the distribution of C_3 and C_4 weeds in different habitats at a particular location is very limited. In the experiment reported herein we tried to classify weeds present at three different crop habitats at a university experimental farm into C_3 and C_4 plants by using the simple methodology for the identification (Yamasue *et al.*, 1979), and attempted to relate the distribution to the conditions of the crop habitat.

MATERIALS AND METHODS

The weed flora of asparagus, trellis-trained grapevine and lowland rice fields were surveyed at the University Experimental Farm situated in Takatsuki City of Osaka Prefecture during July to September, 1980. A part of each field was cleaned by hand weeding at the end of June, and left unweeded thereafter for the weed survey and sampling. Weeds abundant at each field were brought into laboratory at the maturity and their photosynthetic characteristics and leaf anatomy were determined for C_3 and C_4 identification.

In determining the photosynthetic characteristics the leaf chamber shown in Figure 1 was used. The chamber was made from a 500-ml glass cylinder. Detached leaf gently pressed at the base between the rubber stopper halves was fitted into 10-ml flask containing distilled water. After preillumination with fluorescent lamps at 30,000 lux, 28°C for one to two hours, the flask was placed into liquid paraffin in the chamber. The chamber was closed by the silicone stopper and further pre-illuminated for 20 to 30 minutes. The atmospheric pressure inside chamber was equilibrated to the outside through liquid paraffin. On measurement of the photosynthetic rate the air inside chamber was exchanged with standard gas, either CO_2 359 ppm + O_2 21.3% or CO_2 367 ppm + O_2 1.5% v/v, for 5 to 10 minutes at the flow rate of 1.0 ml/sec through the inlent and outlet. After the gas exchange one ml of the internal gas was sampled about every 10 minutes with an airtight gas syringe, and the CO_2 concentration was analyzed in a gas chromatograph equipped with a thermoconductivity detector (150°C, 150 mA). Analytical conditions of the equipment were Porapak Q at 105°C, injection port at 110°C, and the carrier gas at 25 ml/min.

In determining leaf anatomy, leaf segments involving midvein were fixed in FAE solution containing ethanol, acetic acid, formalin, and water (10:1:2:7 v/v/v/v), dehydrated using a tertiary butyl alcohol schedule, embedded in paraffin, and sectioned. Cross-sections, 8 to 12 um in thickness, were stained with safranin-fast green. The observation under a microscope was made particularly on the presence or absence of Kranz structure. Leaf anatomy of several weeds was observed by hand-sections from their specimens.

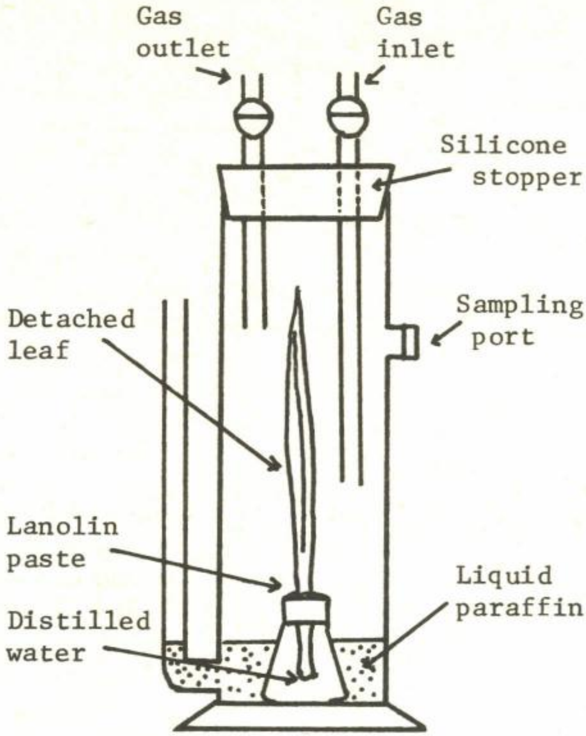

Fig. 1. The leaf chamber used for measurement of photosynthesis by the gas chromatographic method.

RESULTS AND DISCUSSION

Identification of C_3 and C_4 weeds. The change in CO_2 concentration in the closed, illuminated chamber is shown in Figure 2 for *Monochoria vaginalis* var. *plantaginea* and in Figure 3 for *Cyperus serotinus* Rottb. When *Vaginalis* var. *plantaginea* was placed in the chamber containing 21% O_2 the CO_2 concentration progressively decreased for about 15 minutes until no further change in concentration occurred with time. The concentration at this steady state was about 50 ppm and considered as the CO_2 compensation point. However, the CO_2 concentration in the chamber containing 1.5% O_2 decreased more rapidly to a level lower than the minimum detectable limit of the analytical equipment at 10 ppm CO_2. The apparent photosynthetic rate, obtained by the tangential extrapolation at 300 ppm CO_2, was 3.6 $mgCO_2/dm^2/hr$ at 21% O_2 and 9.1 $mgCO_2/dm^2/hr$ at 1.5% O_2. However, the reduction of CO_2 concentration by *C. serotinus* did not differ both at 21 and 1.5% O_2, and the compensation point was not detectable. The apparent photosynthetic rate obtained for this weed was much larger than that of *M. vaginalis* var. *plantaginea* and was 15 $mgCO_2/dm^2/hr$ at 21% O_2. CO_2 compensation point is often used as one criterion distinguishing

C_3 and C_4 plants. Krenzer *et al.*, (1975) measured the compensation points of several hundred species. With two exceptions the points were distinctly divided into two groups: high, 40 ppm or greater; and low, 10 ppm or less. The former corresponds to C_3 and the latter to C_4 plants. On O_2 concentration responses, photosynthetic rate of C_3 plants is inhibited at the atmospheric concentration and this reversible phenomenon is known as the Warburg effect, but there is no apparent Warburg effect in C_4 plants and photosynthetic rate of these plants is not inhibited by O_2 concentration between 1% and up to 100% (Black *et al.*, 1969; Black, 1971; Ishii and Murata, 1978; Matsunaka and Saka, 1977 a). Then, according to these criteria *M. vaginalis* var. *plantaginea* in Figure 2 was identified as a C_3 plant because of its high CO_2 compensation point and Warburg effect, whereas *C. serotimus* was C_4 because of its low compensation point and no effect of the atmospheric O_2 concentration on the photosynthetic rate.

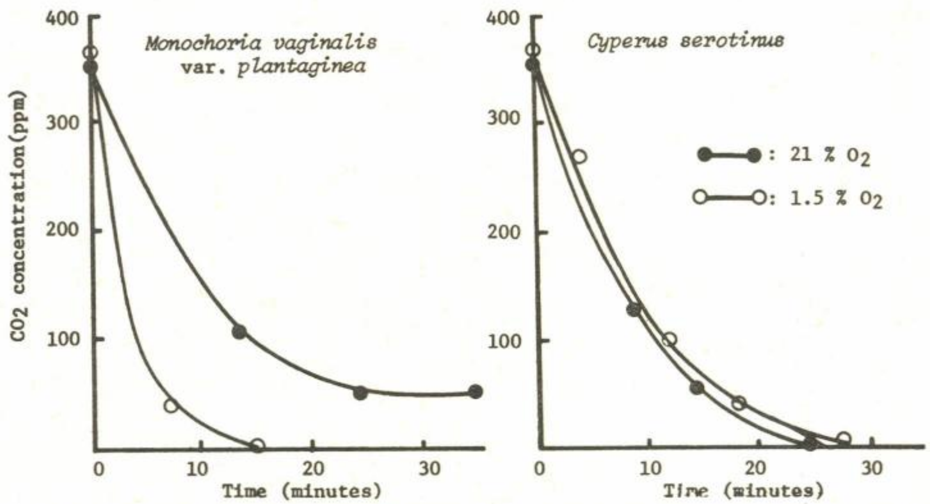

Fig. 2. The change of CO_2 concentration in the leaf chamber with detached leaf of *Monochoria vaginalis* var. *plantaginea*, and of *Cyperus serotinus.*

In addition to the criteria used above, Kranz structure of leaf anatomy is the one most often used in identifying C_4 plants. The vascular bundles are surrounded by chloroplast-containing bundle sheath cells with thick walls and starch granules. Certainly, cross-sections of *C. serotinus* leaf showed the vascular bundles which were enclosed within a layer of thick-walled, elongated bundle sheath cells; Kranz structure. However, *M. vaginalis* var. *plantaginea* did not have the structure in the leaf vascular tissues. The weeds found in the three crop habitats and so identified as C3 and C_4 plants are listed in Tables 1, 2 and 3. As we previously reported (Yamasue *et al.*, 1979), the photosynthetic rates obtained with this method were, however, lower than those recognized in general, and the tangential extrapolation was difficult to use here because of the rapidity in CO_2 reduction in comparison to the time intervals between the injections (Figure 2). Thus, only the rates at 21% O_2 were listed in tables for reference. The presence of Warburg effect was conveniently defined here as the reduction of CO_2 compensation points to levels less than 10 ppm at 1.5% O_2. This was a stable character for all of the C_3 weeds determined. Though it might be questionable in intraspecific difference, the weeds common at two habitats were identified as either C_3 or C_4.

Weed flora. — In asparagus the soil was apparently the most arid among those in the three crop habitats surveyed throughout the experimental period from July to September. The pF values at 15 cm in depth at early afternoons were 1.7 to 1.8 in July, 2.6 to 2.7 in August and 2.4 to 2.7 in September. The most abundant weeds at this habitat included four C_4 plants: *Amaranthus viridis* L., *Digitaria ciliaris* (Retz) Koch, *Setaria viridis rotundus*, and two C_3 plants: *Calystegia hederacea* and *Eclipta prostrata. C. hederacea*, a creeping perennial, crept over shoots of the crop and other weeds, and extended its foliage upon the upper surface of the vegetation. At the between-hills with relatively high moisture content in soil, there emerged a large number of *E. prostrata* at an early period of experiment, but the weed decreased in number and appeared to be stunted as the crop grew to develop foliage densely. Six out of the ten species in total were identified as C_4 plants (Table 1)

In trellis-trained grapevine the soil was shaded by the vine trellis even towards the end of June when our survey was begun, and the relative light intensity was less than 40%. The pF values were not larger than 1.2 throughout the experimental period. The temperatures at 5 cm deep in soil were lower about 4°C than in the asparagus field; 23 to 25°C in July and August. There were sixteen species at this habitats, but among these only three species were C_4 plants; *D. ciliaris*, *Kyllinga brevifolius* subsp. *leiolepsis*, *Microstegium japonicum.* The latter two weeds were present in small numbers. In this shaded habitat *D. ciliaris* tillered less frequently and showed an erect plant form, whereas the same species less shaded in asparagus tillered frequently with a prostrate form. Abundant weeds in this habitat were mostly short C_3 plants and included *Duchesnea chrysantha*, *Oenathe javanica*, *Hdyrocotyle maritima*, *Plantago asiatica*, *Taraxacum officinale*, *Rumex crispus* ssp. *japonicus*, *Polygonum longisetum*, *Commelina communis* and *Acalypha australis* (Table 2). Six C_4 weeds were identified among fourteen species found in lowland rice during the experimental period (Table 3). All of C_4 weeds were either Gramineae or Cyperaceae, and they were *Echinochloa crus-galli* var. *crus-galli*, *E. oryzicola*, *Leptochloa chinensis*, *Paspalum distichum*, *Cyperus serotinus* and *Cyperus iria*. *L. chinensis* and *P. distichum* were mostly present at the places relatively unshaded near ridges of the rice field. Abundant C_3 weeds included *Lindernia pyxidaria*, *Monochoria vaginalis* var. *plantaginea*, *Ammannia coccinea* and Eclipta prostrata. *L. pyxidaria* and *M. vaginalis* var. *plantaginea* had small plant heights and occupied highly shaded spaces under rice canoopy, whereas *E. crus-galli* var. *crus-galli*, *E. oryzicola* and *C. serotinus* were tall and extended the foliage over the top of rice plants.

Table 1. C_3 and C_4 classification of the weeds found in asparagus

Water species	Photosynthetic rate/ ($mgCO_2/dm^2/hr.$)	Presence of Warburg of effect b/	CO_2 compensation point C/	Presence of Kranz structure	C_3 or C4
Amaranthus lividus	— d/	—	—	Yes	C_4
Amaranthus viridis	—	—	L	Yes	C_4
Cyperus rotundus	*20*	*No*	L	Yes	C_4
Setaria virids	14	No	L	Yes	C_4
Calystegia hederacea	3	Yes	H	No	c_3
Eclipta prostrata	9	Yes	H	No	C_3
Digitaria ciliaris	—	—	—.	—	c_4
Cyperus iria	12	No	L	Yes	C_4
Artemisia princeps	—	—	—	No	C_3
Commelina communis	4	Yes	H	No	C_3

a/ At 21%

b/ See the definition in the text.

c/ L, 10 ppm or less; H, 40 ppm or greater.

d/ Not determined.

e/ Indentified in gravevine.

Table 2. C_3 and C_4 classification of the weeds founds in trellis-trained grapevine

Weed species	Photosynthetic rate a/ ($mgCO_2/dm^2/hr$)	Presence of Warburg of effect b/	CO_2 compensation point c/	Presence of Kranz structure	C_3 or C_4
Polygonum longisetum	6	Yes	H	No	C_3
Commelina communis	— d/	—	—	—	C_3 e/
Acalypha australis	6	Yes	H	No	C_3
Kyllinga brevifolia subsp. *leiolepis*	21	No	L	Yes	C_4
Digitaria ciliaris	—	—	—	Yes	C_4
Duchesnea chrysantha	4	Yes	H	No	C_3
Taraxacum officinale	9	Yes	H	No	C_3
Plantago asiatic	10	Yes	H	No	C_3
Oxalis corniculata	3	Yes	H	No	C_3
Microstegium japonicum	10	No	L	Yes	C_4
Paederia scandens	4	Yes	H	No	C_3
Trifolium repens	13	Yes	H	No	C_3
Hydrocotyle maritima	6	Yes	H	No	C_3
Oenan*the javanica*	—	—	—	—	C_3 f/
Rumex crispus subsp. japonicus	—	—	—	No	C_3
Rorippa indica	—	—	—	No	C_3

a/, b/, c/ Refer to Table 1.

e/ Identified in asparagus.

f/ Identified in lowland rice.

Table 3. C_3 and C_4 classification of the weeds found in lowland rice

Weed species	Photosynthetic rate a/ ($gm\ CO_2/dm^2/hr$)	Presence of Warburg effect b/	CO_2 compensation point c/	Presence of Kranz structure	C_3 or C_4
Cyperus serotinus	*15*	No	L	Yes	C_4
Echinochloa crus-galli var. *crus-galli*	8	No	L	Yes	C_4
Cyperus iria	12	No	L	Yes	C_4
Leptochloa chinensis	5	No	L	Yes	C_4
Monochoria vaginalis var. *plantaginea*	4	Yes	H	No	C_3
Cyperus difformis	8	Yes	H	No	C_3
Ammannia coccinea	5	Yes	h	No	C_3
Bidens frondosa	10	Yes	H	No	C_3
Paspalum distichum	16	No	L	Yes	C_4
Eclipta prostrata	— d/	—	—	—	C_3 e/
Echinochloa oryzicola	—	—	L	Yes	C_4
Lydwigia prostrata	—	—	—	No	C_3
Lindernia pyxidaria	—	—	—	No	C_3
Oenanthe javanica	—	—	—	No	C_3

a/, b/, c/ and d/ Refer to Table 1.
e/ Identified in asparagus.

Thirty-five weeds of 19 families were found at the three crop habitats of our experimentlal farm, and they were identified as C_3 and C_4 plants from the CO_2 compensation points, Warburg effect and/or from the leaf anatomical structures. Thirteen out of 35 weeds were C_4 plants and their presence was comprised only of three families: Gramineae, Cyperaceae and Amaranthaceae. All of the Gramineae found within this experiment was C_4 plants, and only one species, *Cyperus difformis* in lowland rice, was C_3 plants among the total five species of Cyperaceae.

C_4 weeds were apparently abundant in asparagus. This may have been largely related to the high ability of C_4 weeds to compete with the crop being grown and with other weeds present. As Black *et al.*, 1979 indicated, C_4 plants can show high competitive ability under the conditions of high light intensity and temperature, and of a low water supply. In asparagus there were such conditions in the summer. There was no heavy shading in the upper portion of the vegetation and was aridity in soil. The atmospheric temperatures often exceeded 30°C in July and August. These habitat conditions allowed C_4 weeds, *Amaranthus viridis* and *Setaria viridis* for the two representatives, to exhibit high competitive ability, and they grew large in height and size. *Eclipta prostrata*, a C_3 weed which initially emerged in large number, decreased in number and appeared to be stunted at the late period of field survey. On the contrary, most of the weeds in grapevine were perennial C_3 plants either with prostrate or rosette form. The habitat conditions of heavy shading, cooler temperature and relatively high moisture in soil favored C_3 weeds having low light saturation points and high water requirement. But the prostrate and rosette forms suggested a significant role of the successive mowings, which had been conducted there several times a year, to determine the weed flora in this habitat.

The water flooding condition in a lowland rice was pointed out to make the crop and C_3 weeds predominate over C_4 weeds in competition (Matsunaka and Saka, 1977b; Yamasue *et al.* 1979). In the rice field surveyed eight out of 14 weeds were C_3 plants, but most of the weeds, including the C_4 weeds, were those among the weeds Arai *et al* (1955) classified either into hydrophytic or hygrophytic weeds. As we reviewed previously (Yamasue & Ueki, In press), these weeds adapting in lowland rice apparently have their own survival mechanisms in seed germination, seedling establishment and reproductive manner, by which they tolerate the waterlogged condition and are protected from field management including weed control measures. Hence, it is concluded that C_4 weeds exhibit high competitive ability and become dominant under their favorable environmental conditions, whereas at a particular hbitat like those with successive mowings or water flooding the weeds having their own survival mechanisms predominate regardless of their pathways for CO_2 fixation.

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TAXONOMY AND ECOLOGY OF SOME RICE WEEDS OF CALIFORNIA

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ABSTRACT

Rice weeds of California are discussed with emphasis on native and introduced species of economic importance. Also shown is the distribution of weeds troublesome in other rice-growing regions but not widespread in California, with discussion of possible ecological causes for their restricted distribution.

INTRODUCTION

Rice is grown in the Central Valley of California. Most of the rice hectarage (91%) is in the northern part, the Sacramento valley, while the remainder is in the southern part, the San Joaquin Valley. The growing season in this area is one of hot, rainless summers.

Rice became a commercial crop in California in 1912 following several years of experimental planting (Barrett and Seaman, 1980). Today the rice industry of California is considered to be worth 500 million dollars per year. In 1982 California had 16.5% of the rice hectare of the United States (216,500 ha.) and produced 23.8% of the total United States rice production (1,662,500 MT) (Anon, 1983).

The soils for rice culture in California are all heavy clay soils with impermeable subsoils. Before 1920 rice was seeded into the fields by drills and grown as an upland crop, but after 2 or 3 years of rice production the fields became so contaminated with dormant seed of *Echinochloa crus-galli* (L.) Beauv., that other crops had to be grown in rotation (Seaman, 1977).

In California *E. crus-galli* is the most serious rice weed because without proper control it seriously reduces rice yields (Davis, 1950 and Kennedy, 1923). Actually there is a complex of *E. crus-galli* in California: *Echinochloa crus-galli* var. *crus-galli*, and two forms of *Echinochloa crus-galli* var. *oryzicola* (Vasing.) Ohwi, an early-flowering form and a late-flowering form.

Today rice is seeded by aircraft and grown continuously submerged in shallow basins, called checks, separated by levees (Miller *et. al.,*). Rice is no longer rotated with other crops in most areas because the continuous water cover, from 5 to 20 cm deep, prevents serious growth of *C. crus-galli* as well as other weeds, such as *Leptochloa fascicularis* (Lam.) Gray, sedges, and broad-leaved species.

In addition to the *E. crus-galli* complex and *L. fascicularis*, the most widespread weeds of rice in California are: *Sagittaria montevidensis* Cham. Schlecht. ssp. *calycina* Englm) Bogin (syn. *S. Calycina* Englm); *Ammannia coccinea* Rottb., *Bacopa rotundifolia* (Michx.) Wettst., and *Najas guadalupensis* (Spreng) Morong.

Most of these weeds are native species that persisted after the poorly drained lands of the Central Valley were converted to rice fields (Barrett and Seaman, 1980). Many of these most abundant rice weeds are species that are somewhat resistant to the herbicides in current use.

With the exception of *Echinochloa crus-galli* var. *crus-galli* which appeared in this state during the Mexican period (1824-1848) all the introduced species of rice weeds have been brought into California in rice seed (Hendry, 1931). *Oryza rufipogon* Griff. apparently was introduced in rice seed from the southern part of the United States. The rest of the introduced species are Eurasian, Old World, or New World tropical forms with minute seeds that are easily carried in the hulls of rice seed. On the Rice Experiment Station at Biggs, California, where experimental rice cultivars are grown in blocks separated by open spaces of water 0.5 m. wide, some imported weed species survive only in these open spaces. They are not found in adjacent dense-growing commercial rice fields where such open spaces do not exist.

Cultural practices are important for controlling weeds in California rice culture. For example, placing nitrogen and phosphate fertilizers below the soil surface at a depth of 5 to 10 cm. is beneficial because fertilizers placed on top of the soil promote the growth of submerged aquatics, such as *N. guadalupensis*, *Chara* spp., and filamentous green algae (Bayer et al., 1979). Careful water management is also an important weed control agent in California rice culture (Davis, 1950; Hill, 1982 and Miller *et al.*). The decision to use deep or shallow water levels must take into consideration a number of factors. For instance, the newer rice cultivars are short statured and require shallower water to establish seedlings than the older, taller cultivars. However, an unlevel, sloping, or irregular grade may allow *E. crus-galli* seeds to germinate in the higher, shallower areas of the checks (Davis, 1950). Also, draining the fields to control filamentous algae may expose the soil and result in germination of *E. crus-galli* seeds. More precise levelling of fields has been done in recent years by laser-controlled land levelling machines.

SPECIFIC WEEDS

POACEAE. Grass Family. Barnyardgrass and watergrass are two common names that have been used in California to include the three forms of *E. crus-galli* that have been recognized. Scientific names have been applied differently by various authors; the following useage of scientific names follows Gould *et al.* (9).

E. crusgalli var. *crus-galli* is the form sometimes called barnyardgrass in a restricted sense. This form is quite variable in appearance, having been introduced many times into California from Eurasia. Moreover, autogamous reproduction in this form perpetuates minor variations in heredity. The inflorescence is erect with a purple color, the spikelets with or without prominent awns. It is abundant on the levees, and also occurs on high, dry spots in the checks. Seed dormancy in this form makes it a serious rice weed; any lowering of the water level in the checks exposes the dormant seed to oxygen and permits some seed to germinate, resulting in significant rice yield reductions.

Two forms of *E. crus-galli* var. *oryzicola*, an early-flowering form and a late-flowering form, were introduced into California from Eurasia and now are widespread weeds of rice.

The early-flowering form, sometimes locally called watergrass, produces seed heads that are markedly lax, bending to one side and without purple color. Seed for next year's weeds shatters into the flooded fields in late June, long before any rice is harvested. In contrast to *E. crus-galli* var. *crus-galli*, there is no dormancy in this seed. But falling into the standing water of the flooded check to a depth of 8 to 10 cm. and remaining continuously submerged, the seed is prevented from germinating. In this manner most of these first two forms of *E. crusgalli* are controlled.

The late-flowering form of *E. crus-galli* var. *oryzicola* (syn. *E. oryzicola* (Vasing.) Vasing.; *E. phyllopogon* (Stapf.) Koss) is sometimes called rice-mimicgrass. It was probably introduced into California with seed of cultivars introduced from the Orient. This form, as the common name indicates, grows at the same rate, and sets seed heads with the same general appearance, as the rice plants. The seed head is erect and lacks purple pigment, making its presence in rice very difficult to detect. Usually the *E. crus-galli* var. *oryzicola* plants are darker green than rice and can be recognized with some practice. The absence of a ligule verifies the identity of any particular *E. crus-galli* var. *oryzicola* plant. The seed of *E. crus-galli* var *oryzicola* has no dormancy and can germinate and emerge through water depths up to 30 cm. (Barrett and Seaman, 1976), making it more difficult to control with water management practices (Seaman, 1977).

Echinochloa muricata (Beauv.) Fern. is native to California but has not become a serious weed of rice. In fact, it has been relegated to the status of a rare species, having been replaced in the wetlands of California by forms of *E. crus-galli.* Plants of *E. muricata* can be found as weeds of ditches in such places as the middle elevations of the western slopes of the Sierra Nevada and in the valleys below the eastern slopes of these mountains in adjacent parts of the State of Nevada.

Echinochloa colona (L.) Link also is not an important rice weed in California, but it seems to be spreading as a terrestrial weed of irrigated and poorly drained areas in the southern part of the state.

L. fascicularis is another serious weed of rice in California, controlled by continuous flooding. A summer annual species native to California, it extends east almost throughout the United States and south through Central and South America to Argentina. The seed of *L. fascicularis* cannot germinate under water with any success, but if the seed has already germinated at the time the checks are flooded, *L. fascicularis* top seedlings can grow up through the water with even better growth than the rice seedlings. Because of this, and the problems caused by the *E. crus-galli* complex, planting the rice using aircraft to broadcast the pre-soaked seed onto flooded checks has become the routine practice in California.

O. rufipogon is not a weed problem in California because of a seed certification program. Certified rice seed is used by practically all the growers in the state and *O. rufipogon* is not permitted in certified seed. In the 10 years before 1932, 28% of California rice seed samples had *O. rufipogon* present at an average of 95 *O. rufipogon* seeds per kg., the highest count being 1060 per kg. (Bellue, 1932). Today *O. rufipogon* appears each year in harvested rice, but only in very minute amounts.

Cyperaceae. Sedge Family. The most serious rice weed in California in the *Cyperaceae* is *Cyperus difformis* L. This annual weed does not appear in the rice fields until there has been submergence for some time. It will become abundant in thin stands of rice, but where aerial seeding and successful growth has produced a thick stand of rice, *C. difformis* will not be established in any great numbers. It can become quite abundant in the open water separating the experiment plots of rice varieties at the Rice Experiment Station.

Two perennial species of *Cyperus* are capable of becoming local weed problems in rice in California. These are: *Scirpus fluviatalis* (Torr.) Gray, and *Scirpus mucronatus* L. Both these species are spread by the formation of seed and persist in the fields by underground tubers. They are found mostly on the levees of the checks or in drainage ditches; rarely if ever in well-grown rice fields.

ALISMATACEAE. Waterplantain Family. S. montevidensis ssp. calycina is native to the Central Valley of California, and also the Mississippi Valley of the Central United States. This annual plant can become abundant in poor stands of rice, and may become a major weed problem in such fields, especially on the west side of the Sacramento River. the fine seed is spread rapidly by wind and water. Other species of *Sagittaria* present in California are perennial species spreading by seeds and persisting by tubers. These perennials would appear to be major rice weeds, but are actually plants of deeper ditches and waste places.

Alisma triviale Pursh is a native perennial that is reported as a weed in rice-growing areas only in California, where it may become locally abundant. It was found on 30 of the 70 properties surveyed in 1976 (Barrett and Seaman, 1976).

NAJADACEAE. Waternymph Family. Of the submerged aquatic weeds of rice, *N. guadalupensis* is the most widespread and abundant. Another submerged aquatic, *Zannichellia palustris* L. a member of the *Zannichelliaceae*, *may also be a weed problem in* local areas.

LYTHRACEAE. Loosestrife Family. One of the commonest native species in shallow ditches is *A. coccinea.* In thin stands of rice this summer annual can become extremely abundant, suppressing the growth of rice seedlings.

Rotala indica (Willd.) Koehne is a widespread weed of rice around the world (Cook, 1979), yet in California it is restricted to the Rice Experimentation Station in the Sacramento Valley, with a single additional spot infestation known. At the Station this weed is abundant on the margins of the rice basins and may extend out further into the rice crop.

SCROPHULARIACEAE. Figwort Family. In a 1976 survey of rice weeds (Barrett and Strother, 1978), 85.7% of the fields were infested with *B. rotundifolia.* Only recently has the taxonomy of this genus as it occurs in California been cleared up (Barrett and Strother, 1978). This annual species was introduced from the central part of the United States and appears to be spreading rapidly as a rice weed. It is more abundant in the Sacramento Valley rice fields, being replaced in the San Joaquin Valley rice areas by the native species, *Bacopa eisenii* (kell.) Penn. These two species of *Bacopa* interfere with the growth of rice seedlings. They flower and mature early in the season and are gone by the time hot weather arrives.

Dopatrium junceum (Roxb.) Buch-Ham. in Benth. is an annual species introduced from Asia in rice seed. It is also restricted to the Rice Experiment Station in the Sacramento Valley.

PONTEDERIACEAE. Pickerelweed Family. Perhaps the most rapidly-spreading rice weed in California is *Heteranthera limosa* (Sw.) Willd. It was apparently introduced with rice seed from the Southern United States. It was first found as a rice weed in California in two areas near a temporary rice station in the Sacramento Valley in 1948 (Tucker and McCaskill, 1967). it is not controlled by the present herbicides used in rice.

Another introduction from Asia is *Monochoria vaginalis* (Burm. f.) Presl. This perennial weed was first reported in 1954 (Tucker and McCaskill, 1955). It too is restricted to the rice experiment station where it is abundant in the open water between the plots of rice cultivars on the station grounds. It has not spread from there. The dense growth of commercial rice under California conditions prevents establishment of this weed.

Some other species that may create locally serious weed problems in California rice, and which may require control by herbicides or careful water management, include: *Typha latifolia L.*, *Potamogeton nodosus* Poir., and *Chara* spp.

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GEOGRAPHICAL VARIATION OF *CYPERUS ROTUNDUS* L. AND ECOLOGICAL PROPERTIES

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ABSTRACT

In order to reveal geographical variation of *Cyperus rotundus* L., essential oils in eight clones of tubers collected from Thailand were analyzed. Four clones collected from dry fields had O-type essential oils, the major components of which are cyperene and cyperenone. On the other hand, sesquiterpene ketones such as cyperone or cyperenone were not detected from the four clones collected from paddy condition in lowland. Evidently, the components of these clones were different from the three chemo types which had been previously reported as H-type, M-type and O-type. Therefore, the above lowland clones were classified as L-type which contained only sesquiterpene hydrocarbones. L-type was also different from the three chemo types in ecological and physiological characters, such as tuber weight, tuber production and plant height.

INTRODUCTION

Cyperus rotundus L. is a persistent weed with a wide adaptability to soil types, soil moisture levels and pH occurring from the tropical region to the temperate region. Recently, we have reported variation in the constitution of essential oils in tubers obtained from the Republic of China and Japan (1981). The major components of sesquiterpenes in the *C. rotundus* tubers used were classified into three chemo types, H-, O- and M-type. The H-type contained mostly α -cyperone and B-selinene, the O-type was composed of sesquiterpenes of cyperene and cyperenone but the M-type contained all of these sesquiterpenes.

Variation in the frequency of distribution was found among the three chemo types. Variation in sesquiterpenes in *C. rotundus* tubers may be due to climatic selection. Geographical factors such as latitude and altitude seem to be involved in the formation of sesquiterpenes in these lines.

Among the three chemo types, there were also differences in ecological and physiological characters such as tuber production, seed production, seedweight and locusta length. The present study was conducted with the objective of clarifying the geographical variation in sesquiterpenes of *C. rotundus* by using clones collected from Thailand and Japan.

MATERIALS AND METHODS

Eight clones of *C. rotundus*, which were collected from Bangkok and surrounding areas in Thailand, in 1981 and 1982, were included in this study. These eight clones were divided into two groups, lowland type and upland type. The former ones were collected in low and wet zones where plants are in paddy condition in rainy season. On the other hand, the latter are always in dry condition all the year round.

Each system tuber was planted in a 1/5000 a Wagner's pot and grown under natural conditions as O-, H- and M-types were. The tubers developed in this way were observed from the morphological point of view and were subjected to analysis of constituents of oils after counting the number of tibers per pot and weighing them individually.

In order to know the relationship between water level in soil and constituents of oils, tubers were grown under two different conditions for 60 days, one group in paddy condition, and the other group with 50% moisture level (regarding paddy state as 100). The tubers of both groups which were grown in such states were also checked for their constituents of oils. The oils were extracted and separated by using the quantitative means of preparative gas chromatography. Identification of the components was made by comparison with the t_R in gas chromatography and mass spectra of the authentic specimens.

RESULTS AND DISCUSSION

As shown in Figures 1 & 2 and table 1, the oils of lowland type collected from Thailand, consisted of only sesquiterpene hydrocarbons, which is quite different from other types O-, H- and M-types.

On the other hand, the oils of upland type, which consisted mainly of sesquiterpene hydrocarbons, turned out to belong to O-type. However, the sesquiterpene hydrocarbons themselves of lowland type nutsedge are similar to the ones of other three types, because both have cyperene (3), a nutsedge specific component, -cubebene (2) and -cadinene (5) in common.

No oxygen-containing terpene was found in lowland type. The reason for this, we assume, is that the biosynthetic pathway of oxygen-containing sesquiterpene is faulty somewhere due to anaerobic condition of the soil. Lowland type nutsedge, which are morphologically different and taller than the other type of nutsedge produce less tubers but bigger ones (0.8g each). It also survived in dry condition.

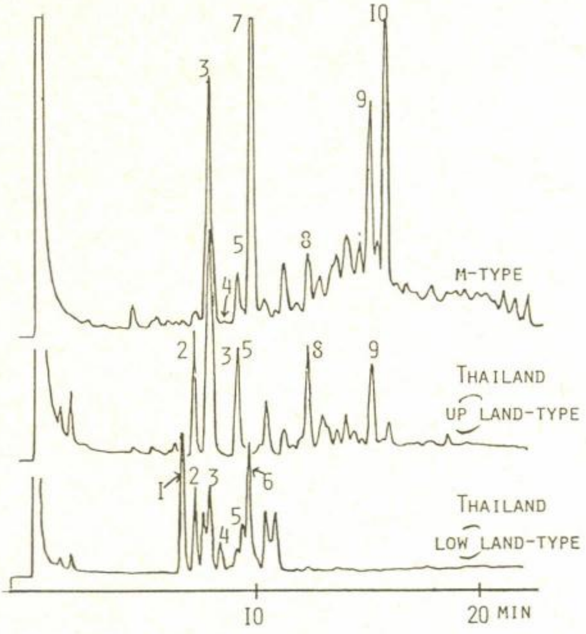

Fig. 1. GLC of essential oils obtained from *Cyperus rotundus* tubers.

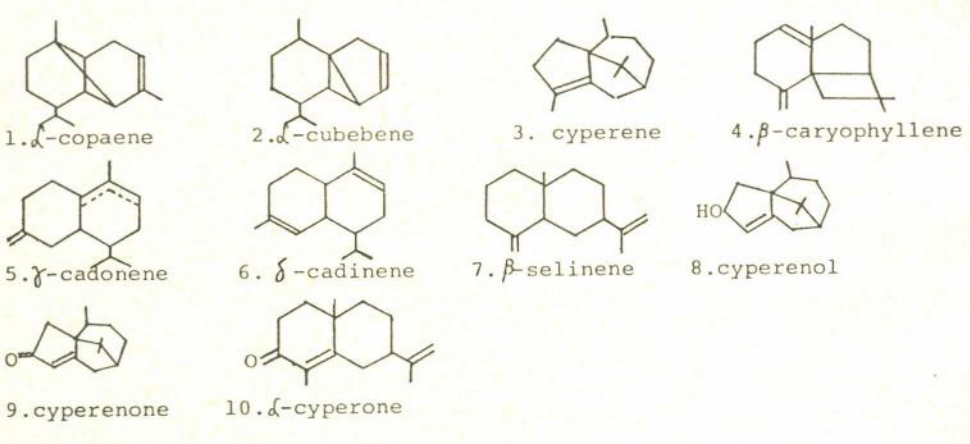

Fig. 2. Chemical structure of sesquiterpenes in essential oils.

O-, H- and M-type tubers can produce new tubers even under lowland conditions and have exactly the same constituent oils as in dryland condition, although there was less oxygen-containing sesquiterpene (Table 3).

Table 1. Chemo-types and components of essential oils.

SESQUITERPENE TYPE (HABITAT)	1	2	3	4	5	6	7	8	9	10
M-TYPE (MIYAZAKI)			++	+	+		++	+	++	++
O-TYPE (OKINAWA)		+	++	+	+			+	++	
H-TYPE (OSAKA)		+		+	+	+	++			++
THAILAND										
UPLAND-TYPE (SIRACHA)		++	++		+			+	+	
UPLAND-TYPE (PAK CHANG)		++	++		+			+	+	
LOWLAND-TYPE (KANPAENSAN)	++	+	+	+	+	++				
LOWLAND-TYPE (BARG PAE)	++	+	+	+	+	++				
LOWLAND-TYPE (BANGKOK)	++	+	+	+	+	+	+			

++ : Strongly Detected, + : Slightly Detected

Table 2. Tuber production, tuber weight and plnta height of each clone. Tuber production was from one parent tuber.

TYPE (HABITAT)	TUBER NUMBER PER POT	TUBER WT. (g)	PLANT HEIGHT (cm)
M-TYPE (MIYAZAKI)	28.1 ± 6.3	0.45 ± 0.29	33.8
O-TYPE (OKINAWA)	38.0 ± 7.6	0.28 ± 0.22	25.3
H-TYPE (OSAKA)	25.6 ± 8.5	0.46 ± 0.30	38.5
THAILAND			
UPLAND-TYPE BANGKOK	37.7 ± 10.7	0.30 ± 0.25	30.6
UPLAND-TYPE BANGKOK	45.5 ± 9.8	0.26 ± 0.20	26.7
LOWLAND-TYPE (HANTRA)	18.3 ± 6.5	0.81 ± 0.44	78.1

Table 3. Sesquiterpenes of essential oils in tuber produced under lowland condition.

	SESQUITERPENE / TYPE (HABITAT)	3	7	9	10
A	M-TYPE (MIYAZAKI)	++	++	±	±
	O-TYPE (OKINAWA)	++		+	
	H-TYPE (OSAKA)		++		+
B	M-TYPE	++	++	++	++
	O-TYPE	++		++	
	H-TYPE		++		++

A; LOWLAND CONDITIONS, B; DRY CONTITIONS SESQUITERPENES WERE DETECTED 30 DAYS PLANTING.

++; SRO STRONGLY DETECTED, + ; SLIGHTLY DETECTED
+; TRACE

As mentioned above, our study shows that upland type among eight clones collected in Thailand belongs to the usual O-type, but the lowland type does not. The constituents of oils of lowland type (L-type) nutsedge are considered to be the most basic ones, mostly sesquiterpenes. Nutsedge is of tropical origin. Many plants of Cyperaceae grow in wet condition. Therefore, it is important to understand the physiological and ecological characteristics of L-type nutsedge in order to develop means of nutsedge control.

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PLANT GROWTH INHIBITING SUBSTANCE CONTAINED[1] IN *POLYGONACEAE* WEEDS

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ABSTRACT

Methanolic extracts from twenty-two *Polygonaceae* weed species showed a strong inhibitory effect especially in the root growth of rice (*Oryza sativa* L 'Tan-ginbozu) seedlings. Methanolic extract of *Polygonum hydropiper* L. was purified by charcoal-celite column chromatography and TLC. The purified substance was identified as polygodial, a sesquiterpene dialdehyde by its UV and IR spectra. This substance possessed a strong piscicidal activity besides a plant growth inhibiting activity. Methanolic extracts of other *Polygonaceae* weeds also showed a piscidical activity. These results suggest that plant growth inhibiting substance contained in *Polygonaceae* weeds can possibly be polygodial.

INTRODUCTION

Family *Polygonaceae* includes many important weed species in Japan, such as *Polygonum hydropiper* L., *P. japonicum* Meisn., *P. conspicuum* (Nakai) Nakai, *P. thunbergii* Sieb et Zucc., *P. nipponense* (Nakai) Makino, *P. sagittatum* L. var. *Seboldii* (Meisn.) Maxim., etc. in lowland and *P. longisetum* De Bruyn, *P. lapathiofolium* ssp. *nodosum* (Pers.) Kitam., *P. aviculare* L., *Rumex crispus* L. subsp. *japonicus* (Houtt.) Kitamura, *R. obtusifolius* L., etc. in upland field (Numata *et al.*, 1975).

These weed species often form a pure community and severely cause weed damage to crops. From such observation, we presumed that these *Polygonaceae* weeds might contain allelochemics which inhibit the growth of other weeds or crops.

This paper deals with some *Polygonaceae* weed species in Japan and showed the possible existence of plant growth inhibiting substance in these plants.

MATERIALS AND METHODS

Materials. Shoots of *Polygonaceae* weeds at flowering stage were collected in Joetsu-city, Niigata-prefecture during August through October, 1982 and kept at -30°C until use.

Bioassay for plant growth inhibiting activity. Frozen plant material was homogenized with five times the amount (w/w) of cold methanol by a universal homogenizer (Nippon-seiki, type HC) twice. Filtered methanol extracts were concentrated in vacuo. From them, an equivalent amount of 0.1, 1 and 5 g fresh material, respectively was taken and poured into a glass vial (18 mm ∮ x 118 mm H) containing 1.5 g of cellulose powder (Toyo, type D) and dried out in a vacuum chamber. Then, 6 ml of distilled water per vial was added and uniformly germinated rice (*Oryza sativa* L. 'Tan-ginbozu') weeds were placed in groups of six. The vials were covered with vinyl film and placed in a growth chamber with a temperature of 30°C and a light intensity of 3000 lux at plant level. Distilled water was added at 1 ml per vial 3 days later and the length of the second leaf sheat and the longest root were measured after another 7 days. Each treatment was duplicated.

Bioassay for piscicidal activity. An equivalent amount of 0.01, 0.1 and 1 g original fresh material of the methanol extract prepared as mentioned above, was taken and dried on a filter paper (Toyo No. 2, 9 cm ∮). The filter paper was soaked in a plastic container (13 cm L x 10 cm W x 6 cm H) containing 200 ml of tap water and ten fish (*Oryzias latipus* L.). The containers were kept at 24°C. Mortality of fish was determined periodically up to 24 hr. after the treatment.

Charcoal-celite column chromatograpy. Concentrated methanol extract (equivalent to 25 g fresh material) was poured on top of the column (14 mm ∮ x 300 mm L) packed with the mixture of 5 g charcoal (Wako, activated charcoal powder) and 10 g celite (Johns-Manville, No. 545). Step elution with water/acetone mixture (V/V) was employed from 50/50 to 0/100 at 10% difference. Every 100 ml eluate was collected and concentrated in vacuo for the use of bioassay or further analysis.

Thin-layer chromatography (TLC). Biologically active fraction of charcoal-celite column chromatography (water 10/acetone 90, V/V) was developed on a silica gel TLC plate (Whatman, LK6) by using benzene/ethylacetate mixture (4/1, V/V) as a developing solvent. Dark-spotted area under UV light was scraped off and eluted with methanol for the use of bioassay, UV (by Shimadzu spectrophotometer, UV-300) and IR (by Shimadzu infrared spectrophotometer, IR-27G) analysis.

RESULTS AND DISCUSSION

Table 1 shows a plant growth inhibiting activity of the methanolic extracts from twenty-two *Polygonaceae* weed species. Root growth in rice seedlings was strongly inhibited by the extracts from most weeds, while the growth of the second leaf sheath was inhibited by the extracts from some species in higher concentration only. These results clearly show the existence of plant growth inhibiting substance (s) in *Polygonaceae* weeds.

To identify the substance(s), further experiments were conducted using *P. hydropiper* plants which possess both piscicidal and plant growth inhibiting activities (Harada & Yano, 1983). Preliminary experiments revealed that this substance was extractable with hot water, methanol, acetone, ethylacetate, ether, chloroform, benzene or n-hexane, and easily partitioned from aqueous solution into organic solvent both at pH3 and 8. From these facts, the substance was considered to be neutral. Methanolic extract was purified by charcoal-celite column chromatography with water/ acetone step elution system. As a result, both activities were mainly shown in the same 10/90 (v/v) eluate and it strongly suggested that single substance might possess both biological activities. Biologically active eluate was concentrated in vacuo and further purified by TLC with benzene/ethylacetate (4/1, v/v) solvent system. As a result, a single spot at Rf 0.59 was detected as a dark color under UV light and a deep yellow color with aldehyde reagent (0.5% 2, 4-dinitrophenylhydrazine in 2N HCl) spray. Spotted area was scraped off and eluted with methanol, then biological activity and UV, IR absorbing spectra were determined. As a result, it showed a very strong psicicidal and plant growth inhibiting activities and pungency. Also, its spectrum data were as follows: UV ; 228 nm, IR 2700 (-CHO), 1715 (satur. C = O), 1975 (LB -unsatur. C=O), 1640 (conj. C=C), 825 (H) cm^{-1}). From these data, biologically active substance contained in *P. hydropiper* was identified as polygodial (Figure 1), which was already reported in the same plant independently of the biological activity (Barnes & Loder, 1962).

To estimate the existence of polygodials in other *Polygonaceae* weeds, a piscicidal activity of the methanolic extracts was examined. All the plants examined showed activity in the following order: *P. hydropiper*, >*P. lapathifolium*, >*P. conspicuum*, >*P. japonicum*, >*P. longisetum*, >*P. filiforme*, >*P. aeranastrum* >*P. perfoliatum*, > *P*, *thunbergii*, >*P. nipponense*, >*P. orientale*, >*P. pubescens*, >*P. lapathioflium* ssp. *nodosum*, >*P. cuspidatum*, >*P. sachalinense*, >*R. crispus*, >*P. nepalense*, >*P. caespitosum* ssp. *Yokusaianum*, >*R. obtusifolius*, >*P. sagittatum*, >*R. Acetosa.* These results suggest that plant growth inhibiting substance contained in *Polygonaceae* weeds is polygodial.

Although roles of polygodials in the growth and allelopathy of *Polygonaceae* weed species are not clarified yet, Sukul (1970) reported that the growth of wheat and the infestation of wheat gall nematode (*Anguina tritici*) were greatly inhibited when they were grown together with *P. hydropiper* and presumed that this inhibition was caused not only by competion for light, water and nutrients but also by toxic root diffusates. A polygodial might be related to this phenomenon.

Table 1. Effect of the methanolic extracts from 0.1, 1 and 5 g fresh weight of **Polygonaceae** *weeds on the growth of rice seedlings cv. Tan-gibonzu (means with standard deviations). Control for second leaf sheath = 13.2 ± 9 mm; for longest root, 69.5 ± 16.3 mm.*

Weed species	Length of second leaf sheath (mm)			Length of longest root (mm)		
	0.1	1	5	0.1	1	5
Polygonum filiforme Thunb.	14.0 ± 0.6	13.4 ± 1.1	12.6 ± 1.1	49.5 ± 6.2	0.8 ± 0.4	0.2 ± 0.4
P. aviculare L.	13.3 ± 1.0	14.2 ± 0.8	14.0 ± 2.7	55.8 ± 3.4	1.0 ± 0.0	0.0 ± 0.0
P. arenastrum Boreau	13.5 ± 0.8	14.3 ± 0.8	11.4 ± 0.9	71.5 ± 11.3	2.5 ± 0.5	0.4 ± 0.5
P. perfoliatum L.	13.3 ± 1.5	0.0 ± 0.0.	0.0 ± 0.0	42.7 ± 5.0	0.0 ± 0.0	0.0 ± 0.0
P. thunbergii Sieb. et Zucc	*11.0*					
P. thunbergii Sieb. et Zucc	11.0 ± 0.0	14.0 ± 0.6	12.2 ± 1.1	75.3 ± 15.0	6.3 ± 2.7	0.0 ± 0.0
P. sagittatum L. var. *Sieboldi* (Meisn.) Maxim.	12.2 ± 0.4	10.0 ± 1.1	9.4 ± 0.9	55.5 ± 10.7	25.3 ± 11.0	0.2 ± 0.4
P. nipponenses (Nakai) Makino	13.7 ± 0.5	14.3 ± 0.8	13.0 ± 0.8	64.2 ± 9.6	1.0 ± 0.0	0.2 ± 0.4
P. nepalense Meisn.	10.7 ± 0.5	11.8 ± 1.2	6.7 ± 0.5	87.0 ± 10.4	21.2 ± 6.8	0.0 ± 0.0.0
P. orientale L.	14.7 ± 1.0	14.8 ± 1.1	10.6 ± 0.9	56.0 ± 11.2	1.0 ± 0.0	0.2 ± 0.4
P. conspicuum INakai) Nakai	11.5 ± 0.5	11.8 ± 0.4	4.5 ± 3.8	33.5 ± 8.9	1.3 ± 0.5	0.0 ± 0.0
P. japonicum Meisn.	11.5 ± 0.5	11.3 ± 0.5	3.7 ± 1.2	19.8 ± 4.0	0.5 ± 0.5	0.0 ± 0.0
O. **hydropiper** L.	11.7 ± 0.8	0.0 ± 0.0	0.0 ± 0.0	32.7 ± 10.2	0.0 ± 0.0	0.0 ± 0.0
P. pubscens Blume	11.7 ± 1.2	10.7 ± 0.8	7.3 ± 1.2	32.8 ± 6.5	1.2 ± 0.4	0.0 ± 0.0
P. lapathifolium L.	12.2 ± 0.4	11.8 ± 0.4	0.0 ± 0.0	31.5 ± 6.0	0.0 ± 0.0	0.0 ± 0.0
P. lapathifolium L. ssp. *nodosum* (Pers.) Kitam.	11.2 ± 1.2	11.8 ± 1.0	0.0 ± 0.0	54.7 ± 9.4	0.5 ± 0.5	0.0 ± 0.0
P. caespitosum Blume ssp.. Yokusaianum (Makino) Danser	11.3 b 0.5	10.5 b 0.5	0.0 ± 0.0	92.0 ± 12.9	17.5 ± 3.3	0.0 ± 0.0
P. longisetum De Bruyn	12.0 ± 1.0	11.2 ± 0.8	9.3 ± 0.5	84.4 ± 6.8	0.8 ± 0.4	0.0 ± 0.0
P. cuspidatum Sieb. et Zucc.	13.0 ± 0.9	13.3 ± 0.8	13.3 ± 0.8	3.3 ± 1.4	79.7 ± 12.2	0.0 ± 0.0
P. sachalinense Fr. Schmidt	11.3 ± 0.5	11.3 ± 0.5	0.0 ± 0.0	47.8 ± 7.7	2.0 ± 0.7	0.0 ± 0.0
Rumex acetosa L.	16.4 b 0.5	10.0 b 2.1	0.0 ± 0.0	70.6 ± 2.6	0.0 ± 0.0	0.0 ± 0.0
R. abtusifolius	14.8 ± 0.4	13.8 ± 0.8	2.3 ± 0.5	53.8 ± 2.5	0.6 ± 0.5	0.0 ± 0.0
R. crispus L. ssp. *japonicus* (Houtt.) Kitamura	11.3 ± 0.5	13.7 ± 0.8	0.0 ± 0.0	54.5 ± 11.2	2.3 ± 0.8	0.0 ± 0.0

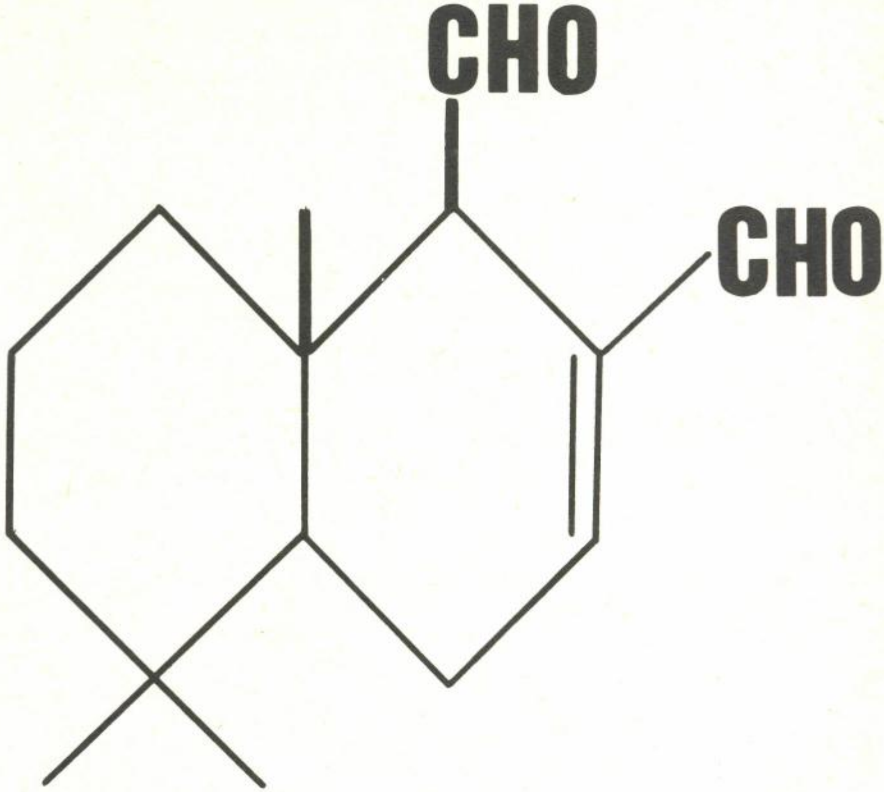

Fig. 1. Chemical structure of polygodial.

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HABITAT, SEED GERMINATION AND GROWTH OF *MIMOSA PIGRA* L. IN THAILAND

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ABSTRACT

Mimosa pigra L. vegetations were found mainly in the Northern Region of Thailand and also in several spots in the Central Region in this survey. Palnts were usually growing at marginal areas of canals, rivers and lakes, but they inhabited water-logged areas and some reservoirs. _M. pigra_ infested abandoned fields and roadsides especially around Chiangmai city. It was found to germinate from soils of various locations, within the soil depth of 7 cm. Seeds could germinate even under 10 cm water depth, but could not establish under flood condition. They could establish only under upland soil condition. After establishment seedlings were very tolerant to flooding.

INTRODUCTION

In recent years, *Mimosa pigra* L. has become one of the most serious weeds, especially in aquatic areas of some tropical places. Known in English as 'Giant mimosa' it is known by several other local names like 'catchlaw,'' 'giant sensitive plant', 'maiyarap yak' in Thai (miller, 1981; Oai, 1982; Robert, 1982; Thamasara *et al.*, 1979).

Although other researchers and officials had collected interesting information from local people and reported them mainly on provincial basis (Napompeth, 1982; Robert, 1982; Royal Irrig. Dept., 1982), it was felt necessary to survey its habitat on vegetation basis. Hence this work was conducted to investigate the potential of *M. pigra* for spreading to other areas, and also to investigate soil and water conditions in which *M. pigra* seeds could germinate and grow.

MATERIALS AND METHODS

Surveys on the distribution of *M. pigra* vegetation and its habitat were done in March to November of 1981 and continued until March of 1983. This species had been reported to occur in several spots around and in Bangkok city (Napompeth, 1982), bu they were only in small populations instead of vegetation so, they were not included in this report.

For germination and growth experiments, seeds were collected from natural habitats in August of 1981, and stored in air-dry condition at room temperature. They were sown after breaking dormancy by soaking in boiling hot water for 5 min. Soil samples were obtained from 7 places in Thailand, and used for germination test under upland condition. Effect of sowing depth in soil on seed germination and emergence was studied at depths of 1, 3, 5, 7, 10, 15 and 20 cm. Effect of water level on seed germination was tested at water depths of 0, 1, 3, 5 and 10 cm. Effect of change of water level on the growth of *M. pigra* seedlings was studied after germinating and growing them under upland condition. At the seedling stages, they were flooded by tap water to get water levels under cotyledon, 1st leaf, 2nd leaf, and so on.

Habitat. — As previously reported (Kittipong, 1980; Napompeth, 1982; Robert, 1982; Royal Irrig. Dept., 1982; Wanichanantakul *et al.*, 1979), *M. pigra* vegetations were found mainly in the Northern Region of Thailand in this survey. They were also found dense along the Ping or the Chao Phraya River down to near Nakorn Sawan city, several spots in the Nan and the Yom Rivers and the Central Region.

M. pigra was found to grow mainly in marginal areas along banks of canals, rivers and lakes, but they also inhabited water-logged areas as seen in some reservoirs. It was certain that they had germinated from soils in upland condition, when water level was low duing the dry season. After germinating, seedlings of *M. pigra* might have been able to develop in flooded condition, as water level rose gradually month by month.

M. pigra infested lots of abandoned paddy fields and roadsides, especially around Chiangmai city in the Northern Region. The density in these habitats are not so much as in other places, but it shows the adaptability of this species to upland field condition. These abandoned fields were once covered with flooded water from *M. pigra* infested Ping River several years ago. For the road construction, much of the river basin sand or soil of *M. pigra* infested areas were widely used and its seeds were spread along new roads. Therefore, major parts of *M. pigra* vegetations should be considered to be aquatic or of aquatic-origin.

Soil experiments. M. pigra seeds had germinated well from all kinds of tested upland and paddy soils. They could emerge and grow only from soil below 7 cm depth, but decayed to die later in soil without emerging.

The results show that they can grow probably on any kind of soil, but that they can not emerge to the soil surface if seeds were buried deeper than 7 cm by cultivation or other practices.

Water level experiments. — When soil was flooded at depths of 0 to 20 cm after *M. pigra* seeds were sown, seeds imbibed water, became swollen and germinated. The radicles and cotyledonary leaves developed to some extent. These cotyledonary leaves were green under water and seemed to be normal. However, germinated seedlings could not establish at the bottom soil under water, because their radicles could not grow into the soil, but curved upwards without attaching or holding on to the soil. These seedlings were detached from swollen seed coats, and usually floated up to the water surface and finally decayed to die later. In our observation, *M. pigra* plants which germinated under flooded water could not establish on the soil, even when they were attached to marginal soil surface above water level after floating. Only a few seedlings were alive in 0 cm flooded soil in this experiment, but their growth was very limited.

Complete flooding over seedlings during 2 weeks (flooded at cotyledone stage), 3 weeks (flooded at 1st leaf stage), 4 weeks (flooded at 2nd leaf stage) and 5 weeks (flooded at 3rd leaf stage) killed all plants in treated pots, but shorter treatments for each leaf stage plants did not kill any. Regrowth was very quick when they were returned to upland condition. On the other hand 3 months flooding were found to kill even large vegetations of *M. pigra* in one reservoir. In our experiment, we used tap water as the flooding water which was clearer than natural river water, so submerged plants in this experiment had surely survived longer than those which were flooded by river water under natural conditions.

Soil surface flooding below the cotyledon or flooding below the leaves did not kill *M. pigra* seedlings, although their root development was considerably inhibited during the period of this experiment.

From the water level experiment, it could be concluded that *M. pigra* seeds could germinate even under flooded condition when their dormancy was broken, but they are unable to grow and establish. Germinated seedlings would float to the water surface without anchoring to the soil and decay later. *M. pigra* seedlings which would germinate soils where water level is lower than soil surface, could grow and establish their stands. Furthermore, after establishing in upland condition, they become very tolerant to flooding if some upper leaves are above the water surface. Even by complete flooding in the rainy season, it would take a few weeks to kill the submerged *M. pigra* seedlings.

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THE BIOLOGY OF *POTAMOGETON MALAIANUS* MIQUEL

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ABSTRACT

There were two distinguished forms of *Potamogeton malaianus* Miquel in Bung Boraped Fishery Station at Chungwat Province, Nakhon Sawan, Thailand. Both forms were very similar in their external structures except in the size of floating leaves, inflorescence and the color of submerged leaves which were remarkably different. Both forms grew very rapidly and propagated by both sexual and asexual reproduction. The results of the ecological study showed that a depth of 1.6 to 3.0 m from the water surface was most suitable for growth and distribution. The maximum biomass was obtained at a depth of 1.6 to 2.0 m from the water surface.

INTRODUCTION

Potamogeton malaianus Miquel commonly known as deeplenam or pondweed, is one of the widespread aquatic weeds in many water resources in Thailand such as Lamtaklong Reservoir, Chulabhorn Reservoir and Bung Boraped Reservoir. Since it is a submerged weed, it is more difficult to control than floating weeds. The spread of *P. malaianus* is endangering the capacity of water resources, and could also threaten aquatic animals by obstructing and limiting food, air, light and shelter. *P. malaianus* is thus a very important aquatic weed partly due to its wide spread and easy propagation by both sexual and asexual means.

The objective of this research was to investigate the morphological and ecological characteristics including seed germination and growth habits of *P. malaianus*.

MATERIALS AND METHODS

The study was conducted at Bung Boraped Fishery Station at Chungwat Province, Nakhon Sawan, and Kasetsart University at Chungwat Bangkok, Thailand. Observations were made on the external morphology of *P. malaianus* (roots, stems, leaves, inflorescences and fruits). The abundance at various depths was also investigated. The biomass production in the Bung Boraped Reservoir was measured. Experiment on seed germination and growth of stems, floating leaves, and inflorescences were performend at Kasetsart University.

RESULTS AND DISCUSSION

There were two distinct forms of deeplenam or pondweed in the Bung Boraped Reservoir. Both forms were generally very similar in their external structures. However, they differed markedly in the size of floating and submerged leaves, inflorescence and color of submerged leaves.

Table 1. Comparison of two forms of Pomatogeton malaianus *or pondweed.*

Plant Part	Form 1	Form 2
Floating leaves		
width of blade	1.4- 3.5 cm	2.0- 4.0 cm
length of blade	9.0-20.3 cm	9.0-22.0 cm
length of petiole	1.1- 3.0 cm	3.0- 9.8 cm
nerves	19	21
Submerged leaves		
width of blade	0.0- 3.5 cm	1.5- 4.0 cm
length of blade	4.0-10.2 cm	10.0-36.0 cm
length of petiole	1.2- 3.7 cm	1.0- 5.7 cm
color of blade	greenish brown	brownish green
Inflorescence		
length of inflorescence	3.0- 6.0 cm	3.5- 8.0 cm
length of peduncle	3.8-10.2 cm	1.5-15.2 cm
number of flowers per inflorescence	30 − 53	30 − 80

Both forms of *P. malaianus* are submerged and are rhizomatous perennials with elongate stems. They are branched, flexible, and erect, and are either floating or creeping. Roots are located at the nodes of rhizomes and stems. Leaves are simple, alternate, with a stipular sheath encircling the stem. There are two types of leaves; the floating leaves which are thick and leathery, and are green, elliptic lanceolate, with palmately parallel nerves and petiolate and the submerged leaves are thin and membranous, linear lanceolate with longitudinal nerves and finer transverse, petiolate. The inflorescence is dense with a cylindrical spike and long peduncles. The flowers are bisexual and small with four perianth segments which are thickened and clawed. There are four 2-celled stamens which are longitudinally dehiscent, sessile and adnate to the perianth at the base. The ovary is superior with two to four carpels which are sessile, free, unilocular, and a single ovule. The stigmas emerge first from the perianth. The fruits and carpels are short beaked. The fruit is a drupe. There are 100 to 200 seeds per inflorescence.

Both forms of *P. malaianus* were widely spread over the Bung Boraped Reservoir. At a depth of 1 to 3 m from the surface growth and distribution of this weed was most abundant (Table 2). At a depth greater than 3.6 m, growth was completely inhibited. Maximum biomass was obtained at 1.6 to 2.0 m from the water surface (Table 3).

Table 2. Relative abundance of P. malaianus *at various water depths.*

Depth of Water (m)	Relative Abundance
0.0 — 0.5	+
0.6 — 1.0	+
1.1 — 1.5	++
1.6 — 2.0	+++
2.1 — 2.5	+++
2.6 — 3.0	+++
3.1 — 3.5	+
3.6 — 4.0	—
4.1 — 4.5	—

Table 3. Biomass of P. malaianus *at various water depths.*

Depth of Water (m)	Fresh Weight (g/m^2)	Dry Weight (g/m^2)
0.6 — 1.0	558.3	47.3
1.6 — 2.0	1556.7	169.3
2.6 — 3.0	1026.7	115.5

Seed germination experiments showed that at 60 days after seeding, the seeds produced a healthy cotyledon. After that, the first foliage leaf appeared at the first node. Stem growth and new shoots from rhizomes appeared 15 days later. A plant can produce 36 to 55 shoots from only one node within 90 days (Figure 1).

Young floating leaves are first found in the stipules on the top of stems. At maturity, they become green, thick and leathery and float at the water surface.

Dense, brownish-pink inflorescence spikes are located in the sheaths at nodes near the water surface. The flowers mature in within 21 to 28 days. Plants can produce flowers all year round which results in large populations.

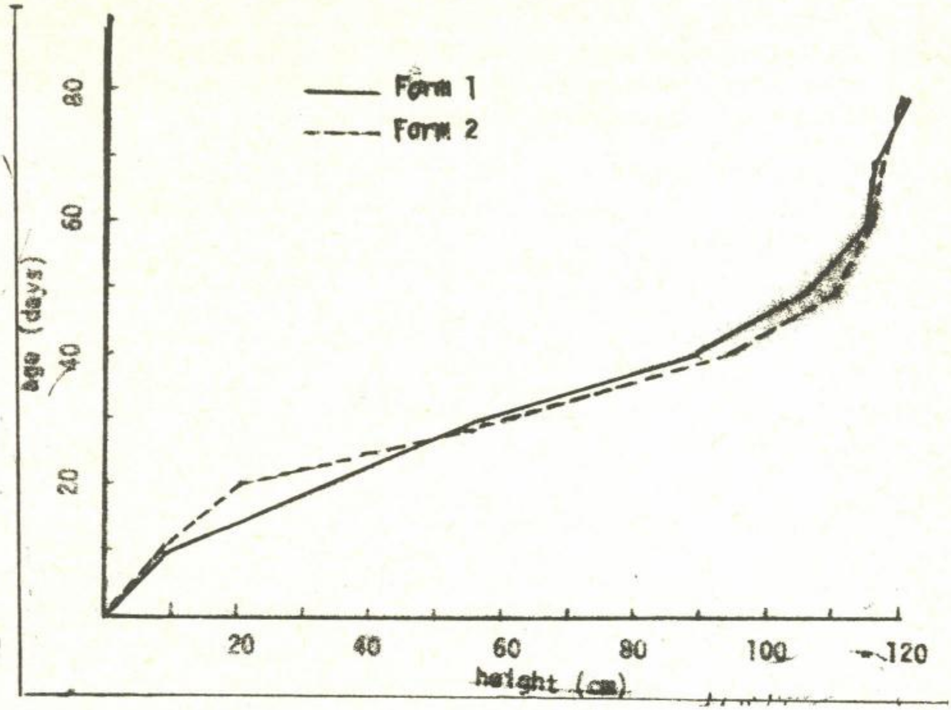

Figure 1. Growth rate of the both forms of *P. malaianus.*

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We are thankful to Nakhon Sawan Fisheries Station, Department of Fisheries for their help in this study. We are also very grateful to Dr. S. J. Mayo, Higher Scientific Officer Herbarum, Royal Botanic Gardens, England, for identification of *Potamogeton malaianus.*

BIOMASS AND PRODUCTIVITY OF A NOXIOUS WEED *ARGEMONE MEXICANA* LINN. FROM THE WASTE LANDS OF VARANASI

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ABSTRACT

Growth of *Argemone mexicana* Linn, a winter annual weed in crop fields and waste lands, was investigated under different environmental conditions. Best growth was observed under open sunlight and high organic matter conditions and in areas having recently deposited soils. The values of biomass and net primary productivity were 122.010 g/plant and 2.1471 g/plant/day. Its sap is acidic, hence can be used for reclaiming saline and alkali soils.

INTRODUCTION

Argemone mexicana Linn. is a winter annual weed, which grows luxuriantly at disturbed places such as waste lands, arable lands, ditches, road sides, grass embankments, field partitions, fallow fields and bunds. It is a problem weed in the fields of gram, tobacco and wheat. This weed causes heavy damage to crops, fisheries, and pastures. Its importance is reflected in its ability to reclaim the Ushar lands which have saline alkaline soils with a pH of more than 8, due to its low sap pH, which ranges from 5.8 to 6.7 (Misra, et al., 1961; Ramamoorthy and Agarwal, 1966; Kaul et al., 1972). These unfertile lands can be converted into fertile ones which can result in more production and in turn contribute to national economy. From this viewpoint the present study is then mainly directed towards the understanding of the interaction of *A. mexicana* with environmental and edaphic factors in relation to its growth performance at different sites with different edaphic and microclimatic conditions.

MATERIALS AND METHODS

The study was conducted in 1980 and 1981 at three different waste lands of Varanasi, India (25 18'N; 83 1'E) on the western bank of the river Ganges, around Banaras Hindu University campus (Table 1). The climate is typically monsoonic, characterized by three distinct seasons (rainy, winter, and summer). During the study period, the maximum rainfall, temperature, relative humidity and sunshine were 49.6 m.m. (January, 38.01 C (May), 94.3! (January), and 10.2 hr. (April) respectively.

Table 1. Characteristics of 3 sites grown with A. mexicana.

Characters	Site 1	Site 2	Site 3
Density	moderate	high	moderate
Organic matter	2%	2.6%	5-7.1%
Porosity	54.3%	31.8%	57.5%
Moisture content	15.1%	4.9%	10.8%
Light (sun)	shady (diffused)	partial shady	open (exposed)

Estimating of plant biomass at all the three sites were made every two weeks by multiple harvest technique. Five plants were harvested, washed to remove the soil, then separated into leaves, stems, roots, reproductive parts (flower & seed), and dead stand. Samples were oven-dried at 65° C for 48 hours then weighed. Standard deviations were calculated for each plant part. The net primary productivity was obtained by calculating differences between successive biweekly biomass values.

RESULTS AND DISCUSSION

The seeds of *A. mexicana*, which remained buried in the soil, germinated in late October and started flowering in late January. Flowering started late at site 1. The plant started drying gradually from the month of April, but dried late at site 1 followed by site 2.

The biomass of plant parts showed an increasing trend in all three sites. Peak values for sites 1, 2 and 3 were 88.13 g/plant, 91.65 g/plant and 122.01 g/plant respectively (Tables 2, 3 and 4).

The peak values of net primary productivity for sites 1, 2, and 3 were 1.698, 1.188 and 1.397 g/plant/day respectively. The values were negative after 165 days for sites 2 and 3, and for the first after 180 days (Tables 2, 3 and 4).

The phenological characters indicated that the species is a winter annual which completes its life cycle within 6 to 7 months. In all the 3 sites, the biomass increased up to a certain age, depending on climatic conditions and then started decreasing (Tables 2, 3 and 4). The decline in biomass after the

Table 2. Biweekly variation in standing crop biomass (g/plant) & net primary productivity (g/plant/day) of plant parts at site 1.

Days	Leaf	Stem	Root	Reproductive parts	Standing	Biomass	Productivity
15	0.01	0.002	0.002	----	---	0.022	0.001
	+ 0.00	b 0.000	± 0.000	----	---	± 0.002	
30	0.11	0.016	0.018	----	---	0.154	0.008
	± 0.01	± 0.001	± 0.001	----	---	± 0.014	
45	0.52	0.120	0.055	----	---	0.698	0.036
	± 0.22	± 0.029	± 0.011	----	---	± 0.260	
60	2.28	0.460	0.220	----	---	2.966	0.151
	± 0.60	± 0.282	± 0.078	----	---	± 0.959	
75	6.36	0.460	0.956	----	---	8.966	0.400
	± 0.64	± 0.395	± 0.126			± 1.663	
90	13.11	3.940	2.796	----	0.668	20.514	0.769
	± 4.57	± 1.044	± 0.153		± 0.086	± 5.755	
105	20.85	7.710	3.980	1.268	0.954	34.762	0.949
	± 5.12	± 0.867	± 0.420	± 0.566	± 0.566	± 6.769	
120	35.25	16.310	5.340	1.950	1.380	60.230	1.697
	± 6.32	± 6.219	± 0.877	± 0.233	± 0.333	±13.435	
135	38.34	22.760	6.720	4.350	2.840	75.010	0.985
	± 9.90	± 4.163	± 0.660	± 0.527	± 0.672	±14.520	
150	29.68	23.970	6.600	13.290	8.214	81.754	0.449
	± 5.03	± 2.920	± 1.096	± 2.396	± 2.001	±10.611	
165	24.51	25.200	6.550	17.180	13.410	86.850	0.339
	± 5.55	± 3.679	± 0.709	± 4.718	± 2.016	± 8.350	
180	15.58	20.950	6.530	18.680	26.399	88.130	0.085
	± 2.72	± 4.069	± 0.795	± 3.258	± 2.802	± 7.880	

Table 2. Continuation

195	4.42	14.670	6.510	12.600	37.160	75.420	-0.847
	± 1.52	± 6.526	± 0.594	± 2.035	± 4.600	± 5.461	
210	0.16	8.580	6.500	4.980	42.880	63.102	- 0.8212
	± 0.08	± 4.648	± 0.475	± 2.299	± .272	± 6.775	

Table 3. Biweekly variation in standing crop biomass (g/plant) & net primary productivity (g/plant/day) of plant parts at site 2.

Days	Leaf	Stem	Root	Reproductive parts body	Standing dead	Biomass	Productivity
15	0.10	0.007	0.005	———	———	0.114	0.007
	± 0.01	± 0.002	± 0.001			± 0.019	
30	0.36	0.032	0.026	———	———	0.427	0.020
	± 0.05	± 0.009	± 0.003			± 0.063	
45	1.38	0.078	0.134	———	———	1.599	0.078
	± 0.11	± 0.020	± 0.013			± 0.144	
60	3.94	0.622	1.464	———	———	6.032	0.295
	± 0.70	± 0.146	± 0.064			±	
75	9.14	3.510	2.732	———	0.538	15.920	0.659
	± 1.94	± 1.106	± 0.094		± 0.109	± 3.061	
90	17.98	9.310	3.840	0.256	2.354	33.740	1.18
	± 4.38	± 2.329	± 0.185	± 0.166	± 0.126	± 7.054	
104	24.34	13.630	5.680	3.370	3.680	50.700	1.131
	± 4.16	± 1.482	± 0.375	± 1.534	± 0.262	± 7.809	
120	34.89	20.650	4.460	5.280	4.360	71.640	1.396
	± 6.72	± 2.857	± 1.370	± 1.817	± 0.243	±12.823	

Table 3. Continuation

135	37.76	22.990	6.580	12.880	4.530	84.740	0.873
	± 9.06	± 4.406	± 1.524	± 3.867	± 0.862	±19.589	
150	ñ 27.58	24.180	6.460	17.940	14.440	89.600	0.324
	± 2.93	± 1.784	± 0.871	± 3.820	± 1.823	± 9.952	
165	15.58	26.960	6.340	18.420	24.250	91.650	0.136
	± 4.91	± 2.560	± 1.355	± 4.621	± 3.363	±10.178	
180	2.06	18.370	6.320	15.410	38.730	80.890	0.717
	± 1.89	± 3.517	± 0.773	± 5.954	± 9.867	± 5.472	
195	---	10.640	6.310	8.150	46.100	71.200	0.646
		± 2.397	± 1.314	± 2.847	± 5.198	± 6.827	
210	---	4.130	6.310	4.950	50.650	66.040	0.344
		± 1.071	± 0.920	± 0.671	± 4.521	± 3.396	

Table 4. Biweekly variation in standing crop biomass (g/plant) & net primary productivity (g/plant/day) of plant parts at site 3.

Days	Leaf	Stem	Root	Reproductive parts	Standing Dead	Biomass	Productivity
15	0.167	0.017	0.0168	——	---	0.203	0.013
	±0.02	± 0.001	± 0.0007	---	---	± 0.0191	
30	0.69						
15	0.167	0.017	0.0168	---	---	0.203	0.013
	± 0.020	± 0.001	± 0.007	---	---	± 0.0191	
30	0.69	0.080	0.228	---	---	0.996	0.052
	± 0.26	± 0.017	± 0.096	---		± 0.375	

Table 4. Continuation

45	1.41	0.70	0.920	---	---	3.126	0.364
	± 0.19	± 0.118	± 0.141			± 0.440	
60	5.58	1.520	1.482	---	---	8.586	0.364
	± 2.67	± 10583	± 0.498			± 3.743	
75	15.71	6.670	3.650	0.368	0.842	27.240	1.243
	± 5.92	± 1.033	± 0.825	± 0.152	± 0.189	± 8.081	
90	25.42	21.090	6.430	1.428	1.324	55.692	1.896
	± 7.69	± 5.299	± 3.048	± 3.111	± 0.354	±19.173	
105	32.61	25.160	8.960	11.854	1.850	80.434	1.699
	± 7.69	± 5.299	± 3.048	± 3.111	± 0.354	±19.173	
120	42.70	ñ880	8.440	23.350	3.270	112.640	2.147
	± 3.71	± 2.198	± 1.161	± 4.594	± 0.774	±11.846	
135	37.18	41.160	8.250	24.180	10.740	121.240	0.573
	± 6.62	± 7.638	± 3.178	± 8.245	± 1.028	±23.693	
150	20.97	39.620	8.210	24.110	29.100	122.010	0.051
	± 2.89	± 4.966	± 1.987	± 6.686	± 3.835	±13.142	
165	8.69	30.280	8.180	21.480	42.120	110.750	0.750
	± 4.34	± 5.156	± 1.784	± 4.256	± 3.890	±11.993	
180	---	12.950	8.160	16.360	54.480	91.950	- 1.253
		± 0.930	± 12218	± 2.424	± 7.055	± 2.605	
195	---	3.420	8.155	12.160	60.620	84.355	- 0.506
		± 2.714	± 1.779	± 3.770	±11.110	± 3.121	
210	---	---	8.155	6.880	61.860	76.895	- 0.497
			± 1.576	± 2.874	± 7.542	±10.072	

peaks were mainly due to litter fall and dispersal of seeds. Tissue decomposition also played a role in decreasing the biomass at later stages. The decreasing trend in root biomass was due to the translocation of food material to reproductive parts after flowering. Thus the trend showed a sigmoid curve over time (Brouwer, 1962; Friend *et al.*, 1962).

The peak values of biomass was lowest at site 1, because of its negative response to shade and high moisture content. The peak values of biomass at site 2 was only slightly more than at site 1 which was due to compact soil and dense vegetation. Site 3 had the highest biomass due to its open nature and recently deposited soil, coupled with high organic matter content. Due to its porous soil, roots found less resistance to spread and thereby biomass was highest in comparison to sites 1 and 2 (Daubenmire, 1959). Due to high soil moisture plants dried up late at site 1 and dried quite earlier at site 3 (Table 1).

A. mexicana had positive response to sunlight and recently deposited soil, coupled with high organic matter (5.0 to 7.1). It showed negative response to moisture content.

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ECOLOGICAL STUDIES OF *MOLLUGO HIRTA* THUNB OF LOW LYING LANDS OF VARANASI, INDIA

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ABSTRACT

Mollugo hirta Thunb is a winter annual weed of low lying lands and river banks in the Gangatic plain, Northern India. It is found both in cultivated and uncultivated fields and interferes with the growth of winter crops. Standing crop biomass, energy content of aboveground (shoot) and belowground (roots) parts increased with age with peak values found at the flowering stage. The trend in the mineral content of the shoot and roots was: K > N > C > P > Na. The concentration of these minerals increased up to the flowering stage and declined thereafter.

INTRODUCTION

Mollugo hirta Thunb is a winter annual weed of low lying lands and river banks in the Gangatic plain, Northern India. The plant grows luxuriantly, flowering and fruiting even in hot season, when most of the surrounding upland herbaceous species die off. It is found both in cultivated and uncultivated fields and interfered with the growth of winter crops cultivated on the river banks and low lying lands. Due to its prostrate and spreading habit it checks the growth of crop plants as well as competes for soil nutrients. Phenology, standing crop biomass, energy content, nitrogen, phosphorus, potassium, calcium and sodium contents in aboveground parts of plant have been worked out at monthly intervals.

MATERIALS AND METHODS

The present study is confined to temporary pond of Varanasi, India 25 18' N latitude and 83 1' E longitude on the eastern part of the upper Gangatic plain. The pond is shallow and is filled up with rain water during monsoon. It was completely dried in the month of November during the study year 1976-77. After drying, the ponds bear herbaceous vegetation.

The climate is typically monsoonic characterized by three distinct seasons; rainy, winter and summer. The maximum rainfall, temperature, and relative humidity were 507 mm (September) 38.6 C (May) and 88% (August), respectively.

Evaluation of plant biomass was made at monthly intervals by a multiple harvest technique. Using a monolith of size 25 by 25 by 30 cm plants were separated into shoots and roots, oven dried at 65 C for 48 hours and weighed. The productivity was calculated by the differences between successive monthly biomass values. Energy content (Cal/g dry weight) was determined using an oxygen bomb calorimeter (Leith 1968). Total nitrogen was estimated by the micro-kjeldahl method (Jackson, 1958). Phosphorus was determined by the "chlorostanous reduced molybdophospheric blue color method" in a sulfuric acid system (Jackson, 1958). Potassium, calcium and sodium contents were determined by flame photometry (Jackson, 1958).

RESULTS

Phenology

The seeds of *M. hirta* which remain buried in the soil, germinated in November after the beds dried. Flowering started in February and continued to April, closely followed by fruit setting and seed formation till the end of June. After the first rain the species disappeared.

Biomass and productivity

Total biomass and productivity of *M. hirta* increased continuously up to March, where peak values of 60.06 and 22.06 g/m^2 respectively were found (Table 1). After attaining maximum biomass, plants entered the declining phase when biomass decreased gradually up to June. The biomass of the roots is much less than the shoot.

The productivity of plant parts increased up to March and after that negative values were found. The maximum productivity of shoots and roots were noted 0.789 and 0.240 g/m^2/day respectively (Table 1).

Energy content

The energy content of the shoot parts is greater than that of the roots (Table 1). Calorific values of shoots and roots ranged between 2339.29 to 3616.23 and 2805.56 to 3196 Cal/g respectively. Energy content increased up to flowering stage.

Mineral composition

The concentration of nitrogen, phosphorus, potassium, calcium and sodium in the plant parts increased up to flowering stage and declined gradually afterwards (Table 2). As compared to the roots, shoot contained

Table 1. Monthly variations in standing crop biomass, productivity and energy content of shoot and roots of **Mollugo hirta.**

Months	BIOMASS (g/m^2)		PRODUCTIVITY (g/m^2/day)		ENERGY CONTENT (Cal/g)	
	aboveground	belowground	aboveground	belowground	aboveground	belowground
December	8.37	2.25	–	–	3126.54	2805.56
January	15.75	7.50	0.238	0.169	3356.35	2925.35
February	35.60	14.60	0.708	0.253	3449.95	2936.12
March	60.06	22.06	0.789	0.240	3511.30	3196.32
April	55.25	21.75	–0.160	–0.010	3616.23	3112.39
May	48.20	18.90	–0.227	–0.092	3529.49	3026.38
June	43.20	15.05	–0.166	–0.128	2339.29	3005.49

Table 2. Monthly variations in mineral contents (%) of shoot and roots of **Mollugo hirta.**

Months	Nitrogen		Phosphorus		Potassium		Calcium		Sodium	
	Shoots	Roots	Above-ground Shoots	Below-ground Roots	Above-ground Shoots	Roots	Shoots	Roots	Shoots	Roots
December	2.73	1.56	0.287	0.208	2.123	1.857	0.412	0.314	0.102	0.049
January	2.85	1.63	0.315	0.215	2.245	1.903	0.423	0.332	0.105	0.055
February	3.25	2.25	0.385	0.228	2.346	2.000	0.440	0.345	0.106	0.055
March	2.55	1.15	0.310	0.208	2.421	2.138	0.456	0.373	0.109	0.090
April	2.25	1.14	0.248	0.148	2.333	2.103	0.411	0.344	0.112	0.102
May	2.21	1.12	0.236	0.138	2.290	1.815	0.373	0.277	0.103	0.081
June	1.83	1.11	0.230	0.138	2.262	1.795	0.334	0.277	0.089	0.071

higher percentage of these minerals. The following trend was observed:

K > N > Ca > P > Na

DISCUSSION

The phenological characters indicated that the species is a winter annual, which completes its life cycle within 6 to 7 months. The biomass of plants including shoot and roots in the present study followed an increasing trend with age and indicated a sigmoid curve. The maximum value of biomass was obtained in March when plants were fully mature. The decline in biomass after the flowering was mainly due to leaf fall.

Due to rapid growth of the plant body, the rate of production also increased, but after flowering the food material manufactured in the leaves was translocated to the reproductive part. Therefore the rate of productivity of the roots declined and rate of production in the later stage decreased till senescense.

The energy content of this species is correlated with plant age and changes in temperature during the life of the plant. Low temperature favors the synthesis of fat following a decrease in carbohydrate (McNair, 1945) and ths may be the reason for the higher energy values up to the flowering stage in March. The energy content also depends upon the mineral composition of the plant body. The increase in percentage nitrogen up to flowering stage also increased the energy content of the plant. Phosphorus in the plant may change the activity of certain coenzymes (Devlin, 1966) which, in turn, may change the protein and fat synthesis in the plant. Thus increased phosphorus in developing a plant may also be responsible for increase in proteins and fats which give a higher energy value.

The results indicate that the decrease in percentage minerals content in plant parts after flowerng is due to the translocation of minerals from older leaves and stem tissues to newly formed flowers and fruits. The greater amount of minerals N, P, K, Ca and Na in the roots is due to the active metabolic state of green tissues.

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REPRODUCTIVE BIOLOGY OF SOME IMPORTANT WEEDS OF WHEAT IN PUNJAB, INDIA

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ABSTRACT

Reproductive potential, fruit and seed morphology have been studied in as many as 26 species of common weeds of wheat in the state of Punjab, India. An average reproductive potential per plant in presently studied species varied from 95 seeds in *Lathyrus aphaca* L. to 7,790 seeds in *Withania somnifera* (L.). Wheat produces only 75 seeds per plant. Troublesome weeds, namely *Avena fatua* L. and *Phalaris minor* Retz, are characterized by 90% frequency, high density and seed production of 132 and 3,823 seeds per plant respectively. In general seeds ranged in size from 0.77 x 0.47 mm in *Sisymbrium irio* L. to 9.08 x 2.19 mm in *A. fatua*. They may show some range in size within the species or may be of two distrinct in sizes as in *A. fatua* and *Medicago polymorpha* L. Some of the fruits or seeds showed adaptation for dispersal by animals, wind, etc.

INTRODUCTION

Some of the important aspects of the reproductive biology, namely reproductive potential, fruit and seed morphology of weeds associated with wheat were studied. Seed morphology included color, size, shape, weight, surface markings and appendages, if any. The present study is a continuation of the author's work on various distributional and biological aspects of weeds of Punjab plains.

Punjab, one of the 22 states of India is primarily comprised of the plain tracts covering an area of 50,376 sq. km. It is located between $29^{\circ}32'$-$32^{\circ}32'$ N latitude and $73^{\circ}52' - 76^{\circ}6'$ E longitude. On the basis of temperature and rainfall, the region experiences semi-arid climate.

MATERIALS AND METHODS

Mature weeds growing in arable lands were collected during April to May, 1982. Ten plants of each species which were looking healthy and facing comparatively less interspecific, intraspecific and intergeneric competition were taken up. Mature fruits and seeds were studied with respect to various morphological characters. For size and weight of seeds averages for fifty readings have been calculated. Term 'seed' is used in broad sense which means not only true seeds but also for equivalent structures which function and appear as seeds.

RESULTS AND DISCUSSION

Presently 26 species of commonly growing weeds in wheat fields, belonging to 25 genera of 15 families of flowering plants have been studied. Data on fruit per plant, seeds per fruit, seeds per plant, size of seeds, weight of single seed and figure numbers are given in Table 1. Out of these, most common are: *Fumaria indica* Presl., *Spergula arvensis* L., *Medicago polymorpha* L., *Melilotus indica* (L.) All., *Vicia sativa* L., *Lathyrus aphaca* L., *Anagallis arvensis* L., *Rumex dentatus* L., *Phalaris minor* Retz. and *Avena fatua* L. (See also Bir and Sidhu, 1979). These weeds offer keen competition to the crop plants for light, mineral nutrients and water as their density is higher than the other species.

Reproductive potential of weeds. Weeds that can produce large populations quickly are better adapted to changing environmental conditions and cultural practices. In the presently studied weed species number of seeds per plant varied from 95 in *L. aphaca* to 7,790 seeds per season in *W. somnifera,* a perennial herb. In the former seeds were 3.44 x 3.14 mm in size and 14.9 mg in weight. In the latter seeds were small sized (2.2 x 1.8 mm) and lighter in weight (0.92 mg).

Troublesome weeds of wheat crop, namely *A. fatua* and *P. minor* were characterized by vigorous growth and produced 132 and 3,823 seeds per plant respectively. Wheat on the average, produced 75 seeds per plant. Depending upon their density, these weeds may reduce wheat yield up to 50%.

Comparison of the reproductive potential of some common weeds of Punjab plains and Calcutta (Table 2) indicates that comparison is of limited value, since individual plants varied greatly in size and seed output is affected by age, moisture, light intensity, biotic factors (Datta & Banerjee, 1976), genetic constitution, edaphic factors, distribution, etc. However, data on seed production are of considerable help in studying crop-weed interaction in the field with respect to reproductive potential.

Seed size. The seeds ranged in size from 0.77 x 0.47 mm in *S. irio* to 9.08 x 2.19 mm in *A. fatua.* Each spikelet of *A. fatua* contained two differently sized seeds. Each fruit of *M. polymorpha* contained four seeds, two are large-sized and two are small-sized. High seed production per plant may be associated with small-sized, lighter seeds and vice versa.

Table 1. Reproductive potential and morphology of seeds in some common weeds of funjab plains, India

	Weed Species	No. of fruits per plant	No. of seeds per fruit	Average No. of seeds per plant*	Weight of single seed** (mg)	Size of seeds** length x breadth (mm)	Characters of seeds
	Family: Papaveraceaea						
1.	*Argemone mexicana* Linn.	20.9± 9.5588	165.3± 31.4044	3454.71	1.51± 0.3951	1.94±0.1505x 1.76±0.1174	Black, globose with beak like projection and have honey-combed surface
2.	*A. ochroleuca* Sweet	15.4± 10.1237	173.1± 29.8680	2665.74	2.29± 0.6419	1.99±0.0738x 1.80±0.0666	Black, globose with beak like projection and have honey-combed surface.
	Family: Fumariaceae						
3.	*Fumaria indica*	181.3± 80.1429	1	181.30	1.33± 0.3603	1.87±0.1159x 1.52±0.0918	Reddish-brown, obovoid with longitudinal streaks and have smooth testa.
	Family: Cruciferae						
4.	*Sisymbrium irio* Linn.	41.4± 14.2999	57.6± 4.1952	2384.64	0.0775± 0.0171	0.77±0.0483x 0.47±0.0674	Yellow, nearly/oval in shape, with small demarcations on the shining surface.
	Family: Caryophyllaceae						
5.	*Spergula arvensis* Linn.	158.8± 94.2380	37.6± 4.2216	5970.88	0.107± 0.0283	1.24±0.1074x 1.20±0.0666	Black, compressed with membranous wing all-around. possess a notch on one side
6.	*Stellaria media* (Linn.) Vill.	28.3± 11.1360	12.1± 2.2828	342.43	0.238± 1.1820	1.21±0.0994x 1.01±0.0738	Brown, reniform, and acutely tubercled with a prominent notch.
	Family: Malvaceae						
7.	*Malva parviflora* Linn.	86.5± 56.64	98.0± 160.6323	847.70	1.636± 0.1014	2.01±0.0994x 1.59±0.0875	Brownish-black, reniform, testa with small whitish wavy striations.
8.	*Malvastrum coromandelianum* (Linn.) Garcke	79.5± 40.3051	12.2± 1.3166	969.9	2.0± 0.6377	1.88±0.0788x 1.38±0.0789	Dark-brown, reniform, with almost smooth testa with minute distant dots.

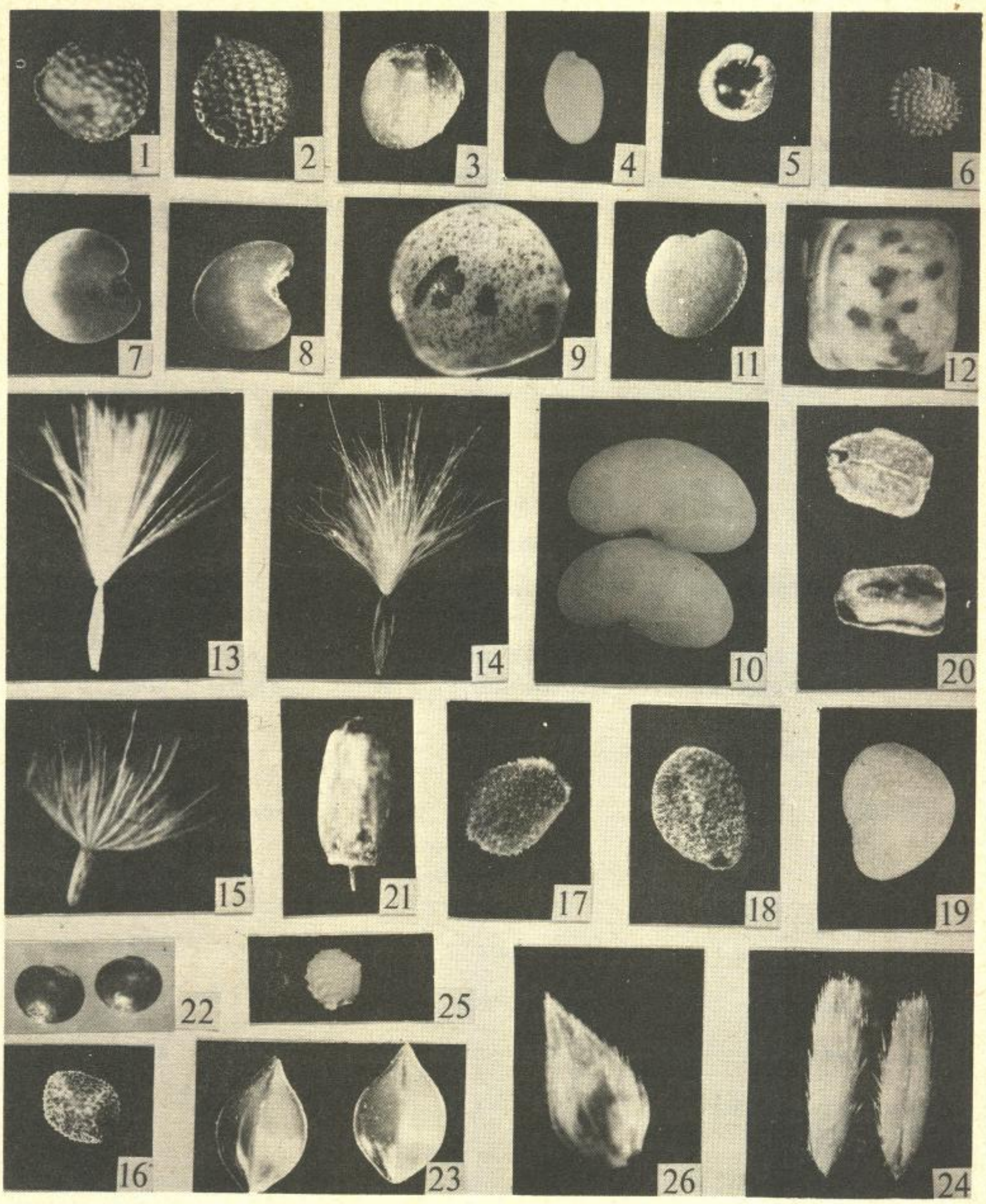
Family: Papilionaceae						
9. *Lathyrus aphaca* Linn.	17.3± 6.3780	5.5± 1.1785	95.15	14.9± 6.0955	3.34±0.2271x 3.14±0.1646	Almost globular, having quite prominent black patches and spots of variables sizes.
10. *Medicago polymorpha* Linn.	61.2± 32.7848	4(2 larger, 2 small)	244.8	4.15± 0.7091 Small: 1.97± 0.3401	4.04±0.1429x 2.11±0.7510 Small: 2.84±0.2273x 1.48±0.0632	Yellow, kidney shaped and distinctly smooth.
11. *Melilotus indica*	281.0± 127.3481	1	281.0	1.58± 0.1135	2.08±0.1032x 1.64±0.3430	Yellowish-brown, nearly ovate with dots of same colour on testa.
12. *Vicia sativa* Linn.	30.7± 12.9631	6.8± 1.7510	208.76	13.57± 2.1817	3.09±0.2355x 2.77±0.1958	Cubical in, shape, smooth with distant black patches of variable sizes.
Family: Compositae						
13. *Launaea procumbens* (Roxb.) Ramayya & Rajagopal	1016.9± 436.4636	1	1016.9	0.21± 0.0309	3.29±0.2183x 0.64±0.9660	Columnar, very thickly ribbed much shorter than the soft straight capillary pappus.
14. *Sonchus asper* (Linn.) Gars.	2479.4± 709.6691	1	2479.4	0.288± 0.2341	3.17±0.4945x 0.80±0.1491	Brownish-yellow, compressed, 3-ribbed, obscurely muricate between the ribs. Pappus copious, slender, simple, usually white united at the base into a deciduous ring.
15. *Tridax procumbens* Linn.	544.6± 166.3124	1	554.6	0.465± 0.0973	2.25±0.0849x 0.68±0.1475	Brownish-black, oblong turbinate, silky pappus of short or long aristate shining feathery bristles.
Family: Primulaceae						
16. *Anagallis arvensis* Linn.	14.6± 4.9486	9.3± 2.8693	135.78	0.406± 0.0164	1.32±0.0788x 0.98±0.0918	Dark brown, many pelate plano-convex with rows of tubercles on the surface.

family: Boraginaceae						
17. *Heliotropium ellipticum* Ledeb.	613.9± 315.9488	4	2455.6	1.34± 0.4624	1.96±0.0966x 1.5±0.2261	Dull black, ellipsoid round at the ends and minutely verrucose.
Family: Convolvulceae						
18. *Convolvulus microphyllous* Sieb, ex. Spreng.	72.0± 27.9603	2.7± 0.4830	194.4	1.76± 0.4376	2.18±0.0632x 1.47±0.8433	Bronish-black, obovate, and minutely puberolous.
Family: Solanceae						
19. *Withania sommnifera* (L.nn.) Dunal	217.8± 37.5345	35.9± 5.5976	7790.3	0.92± 0.1558	2.2±0.1333x 1.83±0.1159	Pale brown, sub-reniform, discoid and polished with dot-like impressions.
Family: Scrophulariaceae						
20. *Antirrhinum orontium* Linn.	15.7± 2.9458	178.0± 13.3666	2794.6	0.107± 0.2830	0.95±0.0707x 0.7±0.0666	Brown, oblong, with one end conical, rugose or pitted.
Family: Amaranthaceae						
21. *Achyranthes aspera* Linn.	1908.9± 744.7953	1	1908.9	2.35± 0.4378	2.8±0.1054x 1.39±0.0567	Brown, sub-cylindrical with coriaceous testa.
22. *Amarantus viridis* Linn.	5790.0± 1095.1612	1	5790.0	0.48± 0.0421	1.14±0.1646x 1.06±0.0699	Black, smooth, shining and lenticular.
Family: Polygonaceae						
23. *Rumex dentatus* Linn.	205.5± 79.6733	1	205.5	0.08± 0.2211	2.38±0.1474x 1.4±0.0816	Brown, acutely triquetrous, and are polished.
Family: Gramineae						
24. *Avena fatua* Linn.	69.9± 23.3638	2 (1 large, 1 small)	139.8	Small: 5.55± 1.6256 Large: 11.98± 1.2968	Small: 6.29±0.3725x 1.48±0.0.3011 Large: 9.08±0.5533x 2.19±0.2131	Brown, oblong with silky hairs on the side and sulcate in the middle of the seed.
25. *+Dactyloctenium*	377.5± 117.3610	1	377.5	0.406± 0.0134	1.1±0.0816x 0.97±0.0823	Light yellow, nearly globose, and rugose.
26. *Phalaris minor* Retz.	3830.0± 1111.3251	1	3830.0	1.275± 0.2017	3.52±0.1135x 1.8±0.2981	Pale yellow to brown, elliptic and covered with distant hairs.

*Mean values of ten readings.

**Mean values of fifty readings.

+Reproductive potential value is per node.



EXPLANATION TO FIGURES

Fig. 1. *Argemone mexicana* Linn.
Fig. 2. *A. ochroleuca* Sweet
Fig. 3. *Fumaria indica* (Haussk.) Pugsley
Fig. 4. *Sisymbruim irio* Linn.
Fig. 5. *Spergula arvensis* Linn.
Fig. 6. *Stellaria media* (linn.) Vill.
Fig. 7. *Malva parviflora* Linn.
Fig. 8. *Malvastrum coromandelianum* (Linn.) Garcke

Fig. 9. *Lathyrus aphaca* Linn.
Fig. 10. *Medicago polymorpha* Linn.
Fig. 11. *Melilotus indica* All.
Fig. 12. *Melilotus indica* All.
Fig. 12. *Vicia sativa* Linn.
Fig. 13. *Launaea procumbens* (Roxb.) Ramayya & Rajagopal
Fig. 14. *Sonchus asper* (Linn.) Gars.
Fig. 15. *Tridax procumbens* Linn.
Fig. 16. *Anagallis arvensis* Linn.
Fig. 17. *Heliotropium ellipticum* Ledeb.
Fig. 18. *Convolvulus microphyllous* Sieb. ex Spreng.
Fig. 19. *Withania somnifera* (linn.) Dunal
Fig. 20. *Antirrhinum orontium* Linn.
Fig. 21. *Achyranthes aspera* Linn.
Fig. 22. *Amaranthus viridis* Linn.
Fig. 23. *Rumex dentatus* Linn.
Fig. 24. *Avena fatua* Linn.
Fig. 25. *Dactyloctenium aegyptium* (Linn.) P. Beauv.
Fig. 26. *Phalaris minor* Retz.

Table 2. Comparison of reproductive potential in some weeds from Punjab plains and Calcutta. Reproductive potential value is per node.

Weed species	Area	
	Punjab plains (Present studies)	Calcutta (Datta & Banerjee, 1976)
Argemone mexicana Linn.	3,454.77	36,685
Achyranthes aspera Linn.	1,908.9	607
Amaranthus viridis Linn.	5,790	6,415
Dactyloctenium aegyptium (Linn.) P. Beauv.	363.56	228

Adaptation for dispersal. Some seeds have special mechanism for dispersal by wind as presence of pappus in most of the members of Compositae. In others, spines or hook like outgrowths on the surface of the fruit or seeds help in their dispersal by animals including man.

Seeds of four weed species belonging to family Papilionaceae are quite distinct from each other. In *Lathyrus aphaca* and *Vicia sativa* seeds had black patches of variable sizes (Figs.9 & 12), while in *Melilotus indica* dot-like impressions of slightly dark color were present (Fig. 11). Seeds of *Medicago polymorpha* were distinctly smooth, yellow and kidney shaped (Fig. 10).

Three species of weeds belonging to family Compositae, namely: *Tridax procumbens, Sonchus asper* and *Launaea nudicaulis,* have been studied. The achenes bore pappus different in size and ornamentatin from each other (Figs. 13-15).

Only three species of family Graminaea, namely: *Avena fatua, Dactyloctenium aegyptium* and *Phalaris minor,* have been studied. Seeds of *A. fatua* were brown, oblong and bear silky hairs (Fig. 24), while in *D. aegyptium* seeds were light coloured small and rugose (Fig. 25). *P. minor* seeds were pale yellow to brown, elliptic and covered with distant hairs (Fig. 26).

Information about fruit and seed morphology plays an important role in soil-seed bank studies as presently studied species canbe easily identified on the basis of above-mentioned characters.

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THE EFFECT OF *IMPERATA CYLINDRICA* (L.) BEAUV. (ALANG-ALANG) RHIZOME DECOMPOSITION ON THE GROWTH OF CORN

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ABSTRACT

Preliminary work in pots indicates that planting corn within 3 weeks after soil cultivation of land dominated by *I. cylindrica* is not desirable because of the microorganisms competing for N (and P) for decomposition. Enough fertilizer is to be applied to satisfy the requirement for decomposition as well as for crop growth.

INTRODUCTION

Land dominated by *Imperata cylindrica* (L.) Beauv. (Alang-alang) in Indonesia is reaching 16 million ha (Soerjani, 1970). *I. cylindrica* grows densely to produce up to 11 tons biomass/ha and 7 tons/ha of root and rhizome. In the minimum tillage shoot and rhizomes are left to decompose.

The substantial amount of decomposing rhizome in soils may interfere with the crop growth (Lynch, 1979). This pot experiment is a preliminary work aimed at investigating the effect of rhizome decomposition on the growth of corn.

MATERIALS AND METHODS

Rhizomes of alang-alang were collected from the field plot, and chopped into small pieces (1-2 cm). Tajar soil was air-dried, sieved (2 mm) and used in this experiment. Five kg of this soil was mixed with 20 g of dried pieces of rhizome cuttings and placed in plastic pots.

The treatments consisted of pots containing soil only (control), soil mixed with rhizome (R), soil mixed with urea fertilizer + TSP at an equivalent of 180 kg N/ha and 145 kg P_2O_5/ha and soil mixed with fertilizer (N + P) and rhizome. These pots were planted to 2 corn seeds 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 weeks after mixing. Treatments were replicated twice and randomised completely. The height and leaf number were.recorded before harvest 4 weeks after planting.

The shoot biomass was dried at 80°C for 48 hours and analyzed statistically.

RESULTS AND DISCUSSION

The presence of decomposing rhizome at 4 g/1 kg soil reduced the dry weight of corn biomass from 2. 4 to 1.1 g/pot (Table 1). However when the mixture was fertilized with urea at 180 kg N/ha and TSP at 145 kg P_2O_5/ha the reduction due to the decomposing rhizome disappeared and the biomass of corn even increased further up to 7.5 g/pot, an increase of more than three times that of the biomass of corn grown in unfertilized soil and was much higher than that grown in soil fertilized with similar rate but without decomposing rhizome.

Table 1. Mean dry weight (g/pot) of shoot corn harvested 4 weeks after planting.

	Time of decomposition (weeks)										
Treatments	1	2	3	4	5	6	7	8	9	10	Mean
Control (0)	2.65	2.10	2.10	2.80	2.50	2.70	2.70	2.20	2.30	1.90	2.4
Rhizome (R)	0.60	0.60	0.75	0.95	1.50	1.00	1.00	1.50	1.80	1.40	1.1
Fertilizer (F)	5.20	5.50	4.80	6.80	6.70	5.30	6.20	5.30	5.40	6.10	5.7
Rhizome + Fertilizer (R + F)	5.05	6.30	6.90	7.75	8.00	7.80	8.30	7.80	7.80	9.70	7.5
Mean	3.39	3.64	3.66	4.58	4.59	4.24	4.44	4.22	4.35	480	

HSD Treatment : 0.30
HSD Time : 0.53
HSD T x T : 1.20

The reduction of corn biomass in the presence of decomposing rhizome may be due to the allelophatic substances released by the decomposing rhizome of *Imperata cylindrica* (Eussen, 1978). In his further works Eussen indicated that the allelophatic substances were phenolics mainly vanillic acid.

Vanillic acid usually occurs in a bound form as glycosides or as esters in plant tissue. The characteristics of vanillic acid and also p-hydroxybenzoic acid was reported by Rice (174). They were identified as allelophatic from *Camelina alyssum* (Grummer & Beyer, 1960), in residue of corn, wheat, sorghum (Guenzi & McColla, 1966) also in *Avena fatua* (Tinnin & Muller, 1972).

Lynch (1976) and Elliot *et al* (1978) considered that the metabolite of decomposing straw could be phytotoxic. Phytotoxic concentration of acetic acid (10 mH) has been reported within 24 hours of the onset of anaerobic decomposition (Lynch, 1979). Toxicity is mainly observed when seedling root came in contact with straw. In this experiment, it was not so since the germination and seedling development was normal. The plant, however, showed a severe nitrogen deficiency symptom. It is more likely that during the decomposition nitrogen is immobilized. This is so since C/N ratio of rhizome is more than 20 while that of the decomposing microorganisms is about 5 (Lynch, 1979). In his work Lynch suggested that to satisfy the decomposition requirement 1.6 g N should be added to each 100 g of straw. If this is operational in this experiment, then the nitrogen required is about 128 kg N/ha. The urea used was 180 kg N/ha which was more than the requirement for decomposition leaving about 52 kg N/ha for soil and corn to utilize. Besides nitrogen, phosphorus seemed to be immobilized also leaving the corn plant to suffer a severe P-deficiency when the soil was not fertilized. The increase of corn biomass grown in soil with rhizome and fertilized at the above rate may be taken as an indication that the problem of reduction of biomass of corn is more due to N or/and P-deficiency rather than the effect of allelophatic substances. However it should be borne in mind that with such a complex system as soil, it is usually uncertain if availability of N only limits the growth, since heterotrophs could remove N by assimilation, proteolysis, denitrification, etc. (Lynch, 1979).

Time of decomposition also affected the production of corn biomass significantly. The first three weeks of decomposition did not affect the biomass of corn. After four weeks of decomposition the biomass showed a steady increasing trend, although there was a slight reduction again in the 6 and 7 weeks of decomposition. It might coincide with the increase of another group of microbial activities in decomposing the rhizome (Lynch, 1979). The reduction was not quite noticeable when fertilizer was added to the soil, since the required nutrient for the decomposing microorganism was supplied. Hence in the analyses of variance, interaction between soil treatment and time of decomposition was significant.

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BIOLOGICAL CHARACTERISTICS OF TROPICAL WEED SPECIES IN THAILAND AND THEIR SIGNIFICANCE IN WEED CONTROL

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ABSTRACT

Some biological characteristics of 113 (31 grasses, 17 sedges, and 65 broadleaves) tropical weed species in Thailand have been investigated in order to develop reasonable weed control techniques. The sedges had relatively smaller seeds compared with grassy and broadleaved ones. The morphological features of the seeds were very variable, particularly in broadleaved weeds. The weed species could be divided into easy-and difficult to germinate-types based on percent germination of seeds at the time soon after ripening. Majority of the seeds were enhanced to germinate under light. ***Euphorbia geniculata*** **Orteg and** ***Hydrophila quadrium*** **were however not affected by light. Some seeds increased in percent germination by scarification treatment. Distinction was made between C_3 and C_4 plants by means of leaf anatomy, particularly the structural features of bundle sheath cell. Further, C_4-like plants of grassy weeds could be distinguished between two types, barnyard-grass type and Eleusine type. Distinction of Cyperaceae weeds between C_3 and C_4 plants appears to be very closely correlated with susceptibility of plants to soil moisture conditions. Many of broadleaved weeds belonged to C_3, but Amaranthaceae and Euphorbiaceae have both C_3 and C_4. Many of the C_3-like plants favor hydro- or hygrophytic condition. Three types of life cycle (long, intermediate and short term) could be distinguished among grasses.**

INTRODUCTION

Effective and economic weed control techniques based on the biological characteristics of particular weed species should be established. This applies not only to chemical control method but also to ecological, biological and mechanical methods. Accordingly, in the National Weed Science Research Project (NWSRI Project) between Thailand and Japan sponsored by Japan International Cooperation Agency that has been started in 1980, researches on the biological characteristics of the princial weed species distributed throughout Thailand were undertaken as one of the major research targets in the project. The weed species considered are not only the most important in Thailand, but also common and universal in the Southeastern Asian countries. The result of this research will provide basic information for establishing adequate weed control techniques in Thailand as well as other tropical Asian countries. Some findings so far obtained would be introduced and discussed in this paper, though being somewhat still preliminary.

Thailand is located in a tropical zone from N 6^{O} to 21^{O}. Therefore, seasonal variation o air temperatures is very little, about 3^{O}C at the maximum temperature and about 5^{O}C at the minium temperature at Bangkok, though those at the Northern areas are to some extent increased. Further, the difference in daylength in a year is also very little, about 2 hrs. On the other hand, notable variation of monthly rainfall in a year is found, as seen in Fig. 1a. A rainy season from May to October amounts to 200 mm precipitation per month on the average, but a dry season from November to March is less than 10 mm per month (Meteorological Dept., MOM, Thailand, 1982).

The above-mentioned climatic conditions seem to influence the ecology and growing behavior of weeds. Particularly, rainfall seems to be the most important factor which governs the life cycle and other biological features of wees.

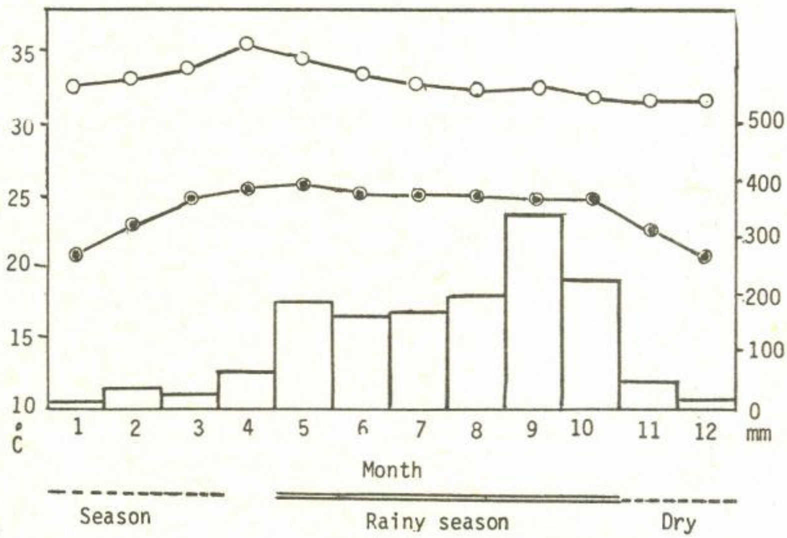


Fig. 1. Monthly Variation of Air-temperature and Rainfall at Bangkok, Thailand (1951-1980)

MATERIALS AND METHODS

The most serious and/or widely distributed 113 weed species in crop and non-crop lands of Thailand have been chosen in this study. They were composed of 31 grasses, 17 sedges and 65 broadleaved weeds. Their seeds were sampled from naturally growing plants thoughout Thailand as well as plants grown in a glasshouse. Germination tests of seeds have been performed within one and two months after sampling under dark and light conditions at about 30°C in an incubator. Seed morphology has been observed by means of light microscope and anatomical observation of vascular bundles and allied tissue portions in a leaf has been done on fresh materials cut by a refriezine microtome as well as permanent slide materials prepared by ordinary paraffin microtechnique.

Life cycles of respective species have been investigated in seeded and transplanted plants at one week interval in the glasshouse at the start of the rainy season.

RESULTS AND DISCUSSION

Seed morphology. The size of seeds is highly correlated with the depth of plant emergence. The longitudinal and transverse lengths and the weight of a seed are given in Fig. 2. Cyperaceae groups is relatively smaller compared with grasses and broadleaved groups. The smallest and largest species by group can be shown in Table 1. *Striga asiatica* (L) O. Ktz and *Sphenochlea zeylanica* Gaertn. is extremely small and *Mimosa pigra* L. is the largest among the species used to this study.

Table 1. Representatives of the larger and smaller weed seeds by group

Group	Scientific name	Width mm	Length mm
Grassy	*Rottoboellia exaltata*	2.943	3.667
	Echinochloa crus-galli	1.821	2.963
	Dactyloctenium aegyptium	0.826	0.931
Cyperaceae	*Scirpus gross*	0.986	1.471
	Cyperus difformis	0.298	0.587
	Fimbristylis miliacea	0.326	0.528
	Cyperus pulcherrimus	0.275	0.475
Broadleaved	*Mimosa pigra*	2.515	5.228
	Phaseolus calcaratus	2.586	3.963
	Sphenochlea zeylanica	0.165	0.473
	Striga agiatica	0.186	0.326

The morphological features are very variable, particularly among broadleaved weed seeds. Their specific morphology and colors should be associated to biological behaviors such as reproduction, longevity and seed spreading, though being in no exact understanding yet. On the other hand, however, those seem to offer effective information to make identification of weed ssed sthat are contaminating crop products and other materials.

Seed germination. Germination and/or dormancy of weed seeds is also closely related to their emergence pattern and growing habits in fields that influence the effectiveness of weed control procedures. In general, seed germination is to be governed by several factors; after ripening of seed embryo, impermeability of seed coats to water and oxygen, existence of germination inhibitors and so on.

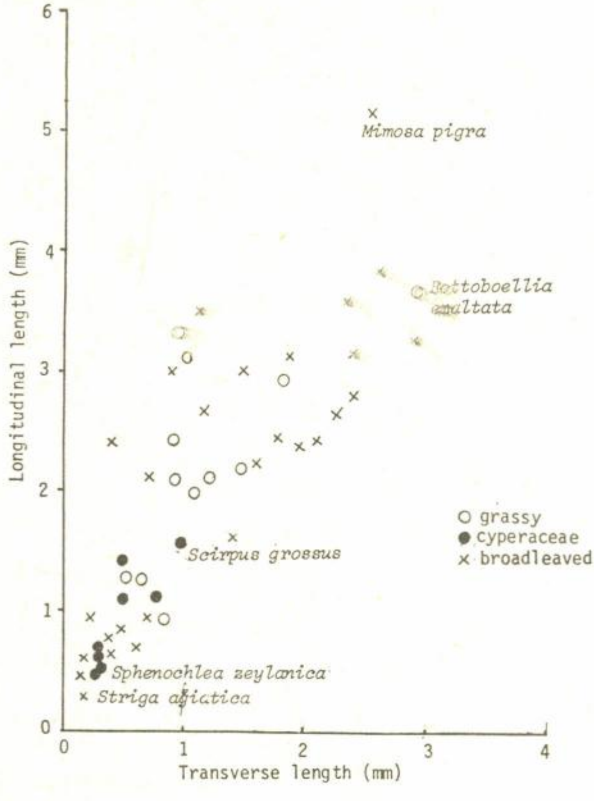


Fig. 2. Variation of the Size of Weed Seeds by Group

In this experiment, it is not aimed to clarify which factors influence on the germination of respective weed seeds, but to learn only the germination properties of tropical weed seeds employed. The result of germination tests performed at two times, one and two months soon after sampling of ripened seeds, gave distinction of easy-germinated and difficult-germinated groups as indicated in Table 2. Easy-germinated seed plants appear to enable repeated life spans in a year to result probably in release of abundant seeds for reproduction. On the other hand, the majority of difficult-germinated seeds seems to be able to acquire increased percent germination within six months according to supplementary tests. Further, some of them, for instance *Monochoria vaginalis* (Burm. F) Presl., would also get high percent germination by scarification against seed coat.

Table 2. Two groups of weed seeds in percent germination soon after sampling (typical examples)

No or low % germination		High % germination	
Eleusine indica	0.8	*Chlorisbarbata*	67.2%
Cenchus echinatus	0.8	*Echinochloa crus-galli*	62.3
Dactyloctenium aegyptium	0.3		
Lepthochloa chinensis	0	*Cyperus iria*	70.4
		Fimbristylis milliacea	95.0*
Scirpus juncoides	0		
Monochoria vaginalis	0	*Hydrophula quadrifolia*	100.0
Mimulus orbicularis	0	*Euphorbia geniculata*	97.7
Sphenochlea zeylanica	0	*Tridax procubens*	69.7
Heliotropium indicum	0	*Trium polygonum*	52.4
Boerhavia diffusa	2.0	*Portulaca oleracea*	67.4
Lagarsia mollis	*5.3*	*Jussiaea linifolia*	76.0

Notes *Figures are the average of two time tests, one month and two months after sampling, two replications under 30 C condition.*

Further, tests under light and dark conditions have shown that the majority of weed seeds used was a light-favor seeds, typical examples of which are indicated in Table 3. No dark-favor seeds were found among weed species used. Two species of *Euphorbia geniculata* and *Hydropila quadrium* provided no essential difference between light and dark conditions. The above mentioned aspect seems to affirm existence of more light-favor seeds than that of dark-favor ones, as already reported (Nakayama, 1960).

Photosynthetic activity. Two types of the photosynthetic CO_2 fixation pathway have been so far regarded to exist in general plants; that is, a conventional Kelvin Cycle pathway, and a C_4-carboxylic acid pathway that was newly discovered by Kortshak *et al.*, 1965), ascertained by Hatch and Slack (1966). Plant groups having the former and latter pathways are called C_3 plant and C_4 plant respectively. Downton (1968) and Tregunna suggested that there is some interrelation between C_3 and C_4 plant metabolism in photosynthesis, phtosynthetic rate, photo-respiration, leaf anatomy, starch distribution and translocation, and further discussed that anatomical methods of leaf provide simple and immediate assays for photosynthetic pathways, many papers indicated that leaf anatomical features are closely correlated with the CO_2 fixation pathways for C_3 and C_4 plants.

On the other hand, another pathway called CAM metabolism has been recently suggested in specific thickened plants which have the highest tolerance to a xerophic condition. Matsunaka and Saka (1977) said that correct decision of C_3, C_4 or CAM plants should be made from multiple standpoints of leaf anatomy, photorespiration, CO_2 compensation point in photosynthesis, and amount of water requirement for growing.

Table 3. Difference in percent germination of weed seeds between Dark and light conditions (typical examples)

Item	Scientific Name	Light	Dark
Much diff.	*Echinochlos crus-galli*	62.2 %	2.5 %
	Chloris barbata	67.2	3.2
	Cyperus iria	70.6	2.5
	*Fimbristylis milliacea**	95.0	0
	*Fuirena ciliaris**	95.0	0
	Euphorbia hirta	33.3	1.0
	Tridax procubens	69.7	2.0
	Portulaca olerace	67.3	10.3
	Jussiaea linifolia	76.0	0
	*Eclipta alba**	83.0	0
Little diff.	*Hydrophila quadrium*	99.0	100.0
	Euphorbia geniculata	97.7	66.0

Notes: Figures are the average of two time tests.
** are the 2nd test only.*

Table 4. Classification of grassy weeds by means of the structure of bundle sheath cells (BSC)

C_4-like plant		C_3-like plant
I (barnyard-type)	II (Eleusine-type)	
Echinochloa crusgalli	*Eleusine indica*	*Leersia hexandra*
E Colona	*Cynodon dactylon*	*Hymenachne pseudointerrupta*
Brachiaria mutica	*Leptohcloa chinensis*	*Orysa* spp. (wild rice)
Cenchus echinatus		
Chloris barbata		
Dactylotenium aegyptium		
Digitaria adscendens		
Heteropogon contortus		
Imperata cylindrica		
Ischaemum barbata		
Panicum repens		
Pennisetum polystachyon		
P. pedicellatum		
Rhynchelytrum repens		
Rottboellia exaltata		
Setaria geniculata		

In general, however, the majority of weedy plants would be discriminated between C_4 plants and C_3 plants by leaf anatomy, particularly existence of chloroplast and/or starch in bundle sheath cell (BSC), because in major species no specific thickened plants seem to be found in general. Classification of weed species into C_3 and C_4 plants should provide basic information with reference to competition ability with crops, adaptability to environmental stress, growing activity and so on.

Thus, anatomical features of leaf in as many as weed species employed was observed. As a result, grassy weeds could be classified into three 1 and 11 types of C_4-like plant and C_3-like plant, though the majority is belonging to the 1 type of C_4-like plant. Anatomical difference between Type 1 and 11 in C_4-like plant was already reported by Noda et al (1973), though the photosynthetic difference is not understood yet. Anatomical difference between them are as indicated in Table 5. Three species of C_3-like plant similar to cultivated rice have been ascertained. They appear to be very interested when taken harber plants against rice diseases and/or pest insects in tropic into consideration.

Table 5: Two types of grassy C_4 plants by means of vascular bundle and/or BSC structure

Item	I (barnyardgrass type)	II (Eleusine type)
Shape of BSC	Round	Square or Ellipse
Size of BSC	Smaller	Larger
Aspect of Chloroplast or Starch Grain in BSC	Centrifugal	Centripetal
Distance between VBS (micron)	64.8-100.8 (81.8)	105.136.8 (117.6)
No. of BSC in large VB	9.4-17.0 (12.5)	8.0-9.3 (8.8)
No. of BSC in small VB	4.4-9.3 (6.4)	5.0-6.7 (5.8)

Cyperaceae weeds could be divided into several groups as indicated in Table 6. Susceptibility to moisture conditions appears to be closely correlated to discrimination between c3 and C_4-like plants. Broadleaved weed species could be classified into C_4 and C_3-like plant as shown in Table 7. Amaranthaceae and Euphorbiaceae have both types. Many of C_3-like plants generally have a favour to hydrophytic and/or hygrophytic conditions, and three species belonging to C_4-like plant have tolerance against a less soil moisture condition.

Life cycle. Ascertaining the life cycle of respective weed plants is also an important and basic knowledge for establihsing effective weed control technology. In particular, the time of seed ripening is greatly associated with the effectiveness and kinds of weed control procedure to prevent the spreading of weed seeds. Thus, the life cycle of weed species employed has been investigated or is under investigation. A final time of weed growing is to be generally limited by a dry condition in winter season, regardless of annul and perennial weeds. Growing patterns are proceeded by several steps of life cycle from emergence to seed ripening. The length of a term from emergence to flowering or ripening is an important standard of the life cycle concerning to weed control.

Table 6. Classification of cyperaceae weeds by means of BSC structure and susceptibility to moisture conditions

Hydrophyte	Hygrophyte	Xerophyte
Cyperus imbricatus	*Cyperus iria* *C. procerus* *C. distans* *Fimbristylis milliacea* *F. dichotoma* *Kyllinga monocephala*	*Cyperus rotundus*
Cyperus difformis *C. pulcherimus* *Scirpus grossus* *S. juncoides* *S articulatus* *Fuírena ciliaris* *Eleocharis dulcis* *Typha angustifolia*		

Annual grassy weed species used in this experiment could be classified into three sorts based on the above standard: longer (90 days <), intermediate (60-80 days) and short (30-60 days) in the number of days from emergence to seed ripening.

Typical examples of respective groups are introduced as follows:

I. Longer : *Pennisetum pedicellatum*
P. polystachyon
Ischaemum rugosum
Setaria geniculata

II. Intermediate : *Echinochloa crus-galli*
Dactylactenium aegyptium

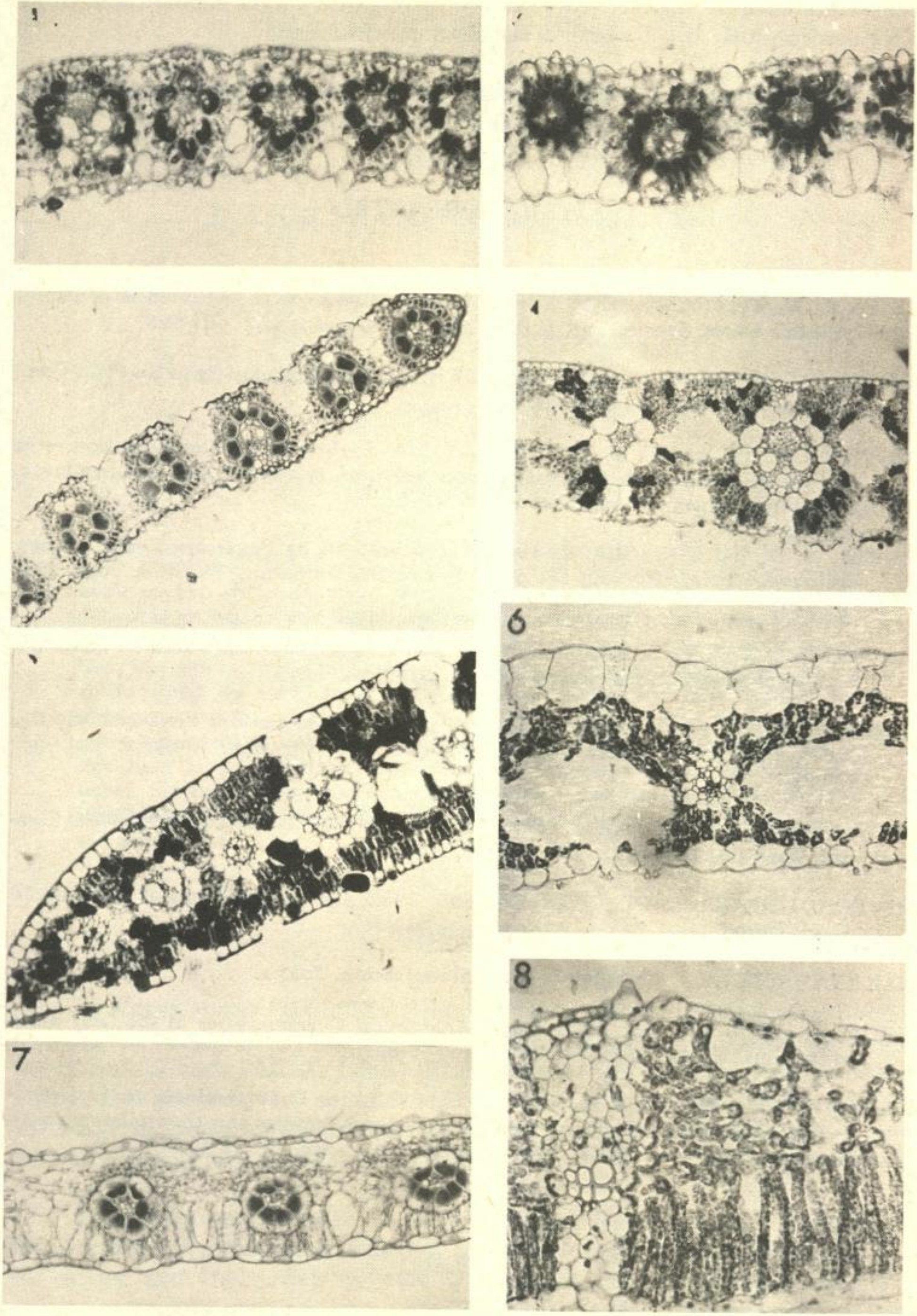
III. Shorter : *Cenchus echinatus*
Eleusine indica
Leptochloa chinensis
Digitaria adscendens

Short groups seem to have possibility of producting a lot of seeds due to repetition of a life cycle in a year, and longer groups like *Pennisetum* spp. can head after vegetative growing of several months and bear abundant seeds at the same of around end of a year.

Table 7. Classification of broadleaved weeds by means of BSC structure by family

Family	C_4-like plant	C_3-like plant
Amaranthaceae	*Amaranthus spinosus* *A. viridis* *Gomphaena celosioides*	*Alternathera philoxeroides** *A. sessiles**
Euphorbiaceae	*Euphorbia hirta* *E. thymifolia*	*Euphorbia geniculata* *Phyllanthus niruri*
Pontederiaceae		*Eichhornia crassipes** *Monocharia vaginalis'* *M. hastala8*
Compositae		Eupatrium odoratum *Tridax procumbens* *Eclipta prostrata** *Sphaenthus africanus*
Mimosaceae		*Mimosa pigra** *M. invisa* *M. pudica*
Commelinaceae		*Commelina diffusa* *C. benghalensis*
(Miscellaneous)	*Boerhavia diffusa* *Portulaca oleracea* *Trianthema portulocastrum*	*Abutilon hirtum* *Aeshynomene indica** *Cleome viscosa* *Crotalaria striata* *Heliotropium indicum* *Lagascea mollis* *Jussiaea repens** *Marsilea crenata** *Pistia stratiotes** *Potamogeton Spp.**

*Note: * Prefer hydrophyte and/or hygrophyte conditions.*



Figures 2-9. Some examples of leaf anatomy. 2. *Brachiaria mutica* (x100, I of C_4), 3. *Echinochloa crus-galli* (x100, I of C_4), 4. *Cynodon dactylon* (x100, II of C_4), 5. *Hymenachne pseudointerupta* (x100, C_3), 6. *Soirpus grossus* (x100, C_3), 7. *Fuerina ciliaris* (x100, C_3), 8. *Euphorbia hirta* (x100, C_4), 9. *Euphorbia geniculata* (x200, C_3).

Further, it is generally said that annual weeds can have perennial like characters because higher temperatures throughout a year enable them to be alive continuously if soil water is supplied continuously.

The life cycles of Cyperaceae and broadleaved weed plants now under investigation would be introduced in a future paper.

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PHYSICOCHEMICAL ASPECTS AND PHYTOTOXICITY OF BUTACHLOR GRANULES FORMULATED IN DIFFERENT WAYS

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ABSTRACT

Butachlor (N-butoxymethyl)-2',6'-diethylacetanilide) granules formulated in two different ways were compared with respect to the physicochemical properties and the phytotoxicity to rice (*Oryza sativa* L.). The sand-coated granule (S-type) was smaller in particle size but heavier in bulk density than the zeolite-impregnated granule (Z-type). A greater phytotoxicity to rice as measured by visual toxicity rating, plant height, and tiller number was obtained with S-type granule compared with Z-type granule. With both granules transplanting of rice at 0.5 cm deep caused a greater phytotoxicity to rice than at 3.0 cm deep. When the two granules were placed in distilled water, the active ingredient was released faster from the S-type granule than the Z-type granule. A similar trend was also obtained with the granules in soil solutions.

INTRODUCTION

In Korea about 80% of total herbicides produced in 1982 were applied in irrigated transplanted rice areas and the rest in upland, orchard, forest and uncultivated lands (ACIA, 1982). The intensive use of herbicides in the rice area is due primarily to: a) economic advantages from rice culture, b) little variation in herbicidal performance under flooded condition, and c) convenience in applying granular herbicides.

Most granules are made either by spraying the active ingredient of the herbicide on to preformed pellets or by moulding from a dough-like mixture of carrier and the active ingredient (Stephens, 1982). Various clays and sands are usually used as the carrier for the purpose. The herbicidal activity of the granules varies with type of formulation and kind and particle size of carriers used (Furmidge, 1972; Konnai, 1972; Mori, 1974).

Butachlor granule has been formulated by impregnating the active ingredient into baked zeolite clay. However, a sand-coated butachlor granule was designed to reduce the production cost. This study was conducted to determine the differences in butachlor phytotoxicity based on the granular formulation and to compare some physical properties of the formulations.

MATERIALS AND METHODS

Butachlor granule. Two granules formulated in different ways were used; Z-type granule containing 6.3% of the active ingredient and S-type granule which was formulated with 1.95% of white carbon, 3.12% of Dialite 300, and 0.1% of RIO or binder in addition to 6.3% of active ingredient. The physical properties such as percent distribution of particles different in size and bulk density were determined according to the methods described by Lee *et al.* (1975).

Phytotoxicity of the granules. An experiment was initiated in the greenhouse to compare the phytotoxicity of Z-type granule with that of S-type granule. An air-dried sandy loam soil with a pH of 5.4, an organic matter content of 0.93% and a CEC of 10.3 meq/100g was placed in a plastic pot (24 cm diameter).

Three seedlings of rice (cv. Seokwang, indica-japonica; three to four leaf stage) per hill were transplanted in the pots at 0.5 cm deep. There were three hills in a pot. One hundred kg/ha of nitrogen was applied in equal splits, basally and at 15 days after transplanting (DAT). Water depth was maintained at 2 cm during the experimental period. Application of butachlor granules was done at the rates of 0.9, 1.8 and 3.6 kg a.i./ha DAT. There were four replications. Visual toxicity rating was taken 10 days after herbicide application and plant height and tiller number were taken 30 DAT.

Butachlor dissolved in distilled water. One hundred mg of the butachlor granules was placed in 100 ml of distilled water. The amount of butachlor released in the distilled water was determined at 3, 6, 24, 48 and 96 hours after herbicide application using gas chromatograph.

Butachlor dissolved in soil solution. This experiment was done in two types of soil; one was a sandy loam soil used in the above experiment and the other a clay loam soil with a pH of 5.7, an organic matter content of 1.13% and a CEC of 13.6 meq/100 g. One hundred g of the air-dried soil was placed in a 1 L Erlenmeyer flask with 500 ml of distilled water and one hundred mg of the granules was added to the flasks. After sealing the flask with a rubber stopper, the flask was shaken mechanically for 24 hours. Then the amount of butachlor dissolved in the soil solution was measured using gas chromatograph.

Gas chromatographic analysis. Butachlor was quantitatively determined by gas chromatography (TRACOR Model 550) equipped with electroncapture detector. Operating temperatures were: injector and detector, 230 and 290°C. respectively; column, 210°C. Carrier gas flow rate was 70 ml/min. The column used was borosilicate (60 cm x 0.4 cm) with packing material of 5% OV-17 on 80-100 mesh Chromosorb W. At chart speed of 6 mm/min, retention time of butachlor was 2.8 min.

RESULTS AND DISCUSSION

Particle size and bulk density of the granules. S-type granule contained more smaller particles than Z-type granule (Table 1). The percent distribution of particles smaller than 32 meshes was 55.8% with S-type and 25.1% with Z-type granule, whereas S-type and Z-type granules contained 1.9% and 0.16% of particles larger than 14 meshes, respectively.

Table 1. Percent distribution of zeolite-impregnated and sand-coated granular particles of butachlor different in size

Particle size (mesh)	Percent distribution	
	Granule type	
	Zeolite-impregnated	Sand-coated
↗12	0.01	0.4
12 – 14	0.15	1.5
14 – 16	5.44	3.5
16 – 24	28.3	11.5
24 – 32	40.9	27.3
32 – 48	18.9	42.9
48>	6.3	12.9

In addition, the bulk density was 1.26 with S-type granule and 1.07 with Z-type granule. Although S-type granule was smaller in particle size than Z-type granule, the former appeared to be heavier than the later.

Phytotoxicity. A greater herbicidal injury was obtained from S-type granule compared with Z-type granule at both transplanting depths tested (Table 2). Increase in the rate of the herbicide application resulted in increasing toxicity while with both formulations the deeper the transplanting depth, crop injury was less at all rates of butachlor application. Similarly, plant height and tiller number were significantly greater with Z-type granule than with S-type granule at the same rate of butachlor application. Decrease in plant height and tiller number caused by application of the granules was more obvious when the rice seedling was transplanted at 0.5 cm deep than when it was transplanted at 3.0 cm deep.

Table 2. Effect of zeolite-impregnated and sand-coated granular butachlor on crop tolerance, plant height and tiller number of rice at different transplanting depths

Type of formulation	Application rate (kg a.i./ha)	Visual toxicity rating[a)]		Plant height (cm)[b)]		Tiller number (no./hill)[b)]	
		Transplanting depth		Transplanting depth		Transplanting depth	
		0.5 cm	3.0 cm	0.5 cm	3.0 cm	0.5 cm	3.0 cm
Zeolite-impregnated	0.9	0	0	38.1a	43.4a	35a	39a
Zeolite-impregnated	1.8	2	0	33.8b	41.7a	31b	37a
Zeolite-impregnated	3.6	3	1	24.2cd	41.5a	25c	30b
Sand-coated	0.9	1	0	33.6b	41.8a	30b	35a
Sand-coated	1.8	2	1	27.9c	37.4b	26c	29b
Sand-coated	3.6	4	2	20.5d	35.3c	23c	28b

a) Rated 10 days after herbicide application on a scale of 0-10 where 0 = no toxicty and 10 - complete kill. b) Means within a column followed by a common letter are not significantly different at the 5% level using Duncan's Multiple Range Test.

Butachlor dissolved in distilled water. There was more and faster release of butachlor from S-type granule into the distilled water than from Z-type granule (Fig. 1). In the first three-hour exposure the amount of butachlor released from S-type granule was four times that released from Z-type granule. In 48 hours a rapid increase in the amount of butachlor in distilled water was observed with S-type granule. However, there was no great change in the amount of butachlor dissolved in distilled water with Z-type granule during the period.

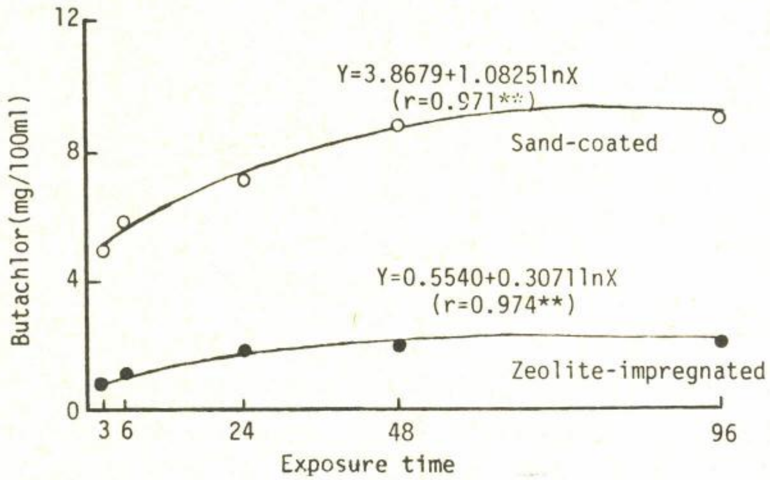

Fig. 1. Amount of butachlor dissolved in distilled water at different exposure times.

Butachlor dissolved in soil solution. The amount of butachlor dissolved in soil solution was significantly greater when S-type granule was applied in two soil types tested than when Z-type granule was applied (Fig. 2). However, there was no significant difference between the amounts of butachlor in the soil solutions of the two soil types no matter what type of the granule was applied.

The main use of herbicide granules has been for the slow release of total herbicides in sites applied and for efficient application (Stephens, 1982). The granular formulation of a herbicide is important in determining whether it is selective or not, since the selectivity may be changed somewhat as a result of the carrier used (Muzik, 1970; Klingman and Ashton, 1975). Furmidge (1972) reported that the granule size was more important in achieving biological effectiveness than either the percentage of active ingredient or the dose rate for the herbicides. As expected based on the results with the two butachlor granules, differences in particle size and bulk density would result in not only less accurate and uniform distribution by granule applicators but also an adverse phytotoxicity. The great phytotoxicity to rice caused by S-type granule was due to both fast release of active ingredient from the granule and high amount of the active ingredient in the soil solution.

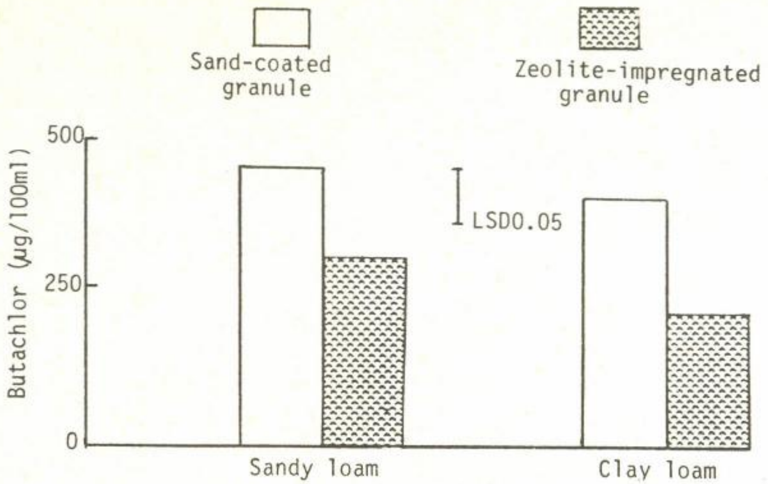

Fig. 2. Amount of butachlor dissolved in soil solutions of two soil textures.

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DEVELOPMENT OF PADDY RICE HERBICIDE MIXTURES WITH BUTACHLOR IN JAPAN

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ABSTRACT

Butachlor mixtures with pyrazolate and naproanilide offer an excellent solution to current rice weed control problems in Japan. These mixtures provided long lasting, broad spectrum weed control with one-shot application flexibility.

As a result of these studies and other official trials in Japan, three new herbicide mixtures have been registered and commercialized in Japan. Kusakarin 25 G and Kusakarin 35 G are granular mixtures of butachlor/pyrazolate at ratios of 2.5%/6% and 3.5%/8% respectively and Oza G is a mixture of butachlor/naproanilide at a ratio of 3.5%/7%. All three are recommended at the standard use rate of 30 kg/ha.

These products were first commercialized in 1982, and are rapidly being adopted by rice farmers as the preferred method of annual and perennial weed control in rice. These products may offer potential for control of troublesome weeds in rice systems in other areas of the world also.

INTRODUCTION

It has been 25 years since herbicides were introduced for weed control in rice in Japan. Today 100% of the rice is treated at least once per season with a herbicide with a total herbicide usage of over 200% of the total rice planted area. The herbicides used were mainly for controlling annual weeds, consequently infestations of troublesome perennial weeds such as *Scirpus juncoides* Roxb., *Cyperus serotimus* Rottb. and *Sagittaria pygmaea* Miq. became more severe (Table 1).

In order to control annual and perennial weeds, farmers began to systematically apply herbicides two or three times per season using a different herbicide for different weed species at each application time (Table 2). For the past several years, herbicide research has concentrated on the development of products which provide broad spectrum control of annuals and troublesome perennials with one application.

Butachlor [2-chloro-2', 6'-diethyl-N-(butoxymethyl) acetanilide] has been widely used in transplanted rice in Japan for control of annual weeds such as *Echinochloa crus-galli* (L.) Beauv., however it does not control *Sagittaria* spp. and occasionally its efficacy is unstable on species such as *S. juncoides* and *C. serotinus* for long-term control and *M. vaginalis* (Burm. f.) Presl. under certain conditions. The objective of this study was to develop products of butachlor mixtures which provide broad spectrum, long-term control of annual and perennial weeds with a single application.

Table 1. Shift of rice problem weeds in Japan[1]

Weed species		Infested area	
	1972 (%)	(%)	1982
Annual weeds			
Echinochloa crus-galli (L.) Beauv.	(E.c.)[2]	95	87
Monochoria vaginalis (Burm. f.) Presl.	(M.v.)	46	33
Cyperus difformis L.	(C.d.)	36	20
Other broadleaved weeds	(O.B.L.)	68	55
Perennial weeds			
Eleocharis acicularis (L.) Roem. & Schult	(E.a.)	43	34
Scirpus juncoides Roxb.	(S.j.)	8	41
Cyperus serotinus Rottb.	(C.s.)	10	24
Sagittaria pygmaea Miq.	(S.p.)	11	37
Sagittaria tripolia L.	(S.t.)	9	20
Eleocharis kuroguwai Ohwi	(E.k.)	< 1	10
Alisma canaliculatum A. Br. & Bouche	(A.c.)	2	16
Potamogeton distinctus A. Benn	(P.d.)	2	6

1: JAPR fact-finding reports on paddy weed control.
2: Abbreviations of word in the following tables.

Table 2. Change in the use pattern of rice herbicides in Japan[1]

Year	Applied area (%)	Application time per season: Once (%)	Twice (%)	3-4 times (%)
1972	100	68	31	1
1982	100	17	64	19

[1] JAPR fact-finding reports on paddy weed control.

METHODS AND MATERIALS

Field tests were conducted at three to seven locations per year from 1977 through 1981 throughout Japan. Infested fields with varying soil types and water percolation properties were selected by targeted weed species.

Rice seedlings at 2-1/2 to 3-1/2 leaf stage were transplanted by machine. Plot size was 2.5m x 2m each year except for 1981 when the plot size was expanded to 10m x 10m. A randomized complete block design was used with 3 replications except in 1981 when only 2 replications were used.

Herbicide mixtures were applied in 1977 and 1978 by mixing the two granular formulations together and applying as a mixture. From 1979 through 1981 herbicide mixtures were formulated into a single product and applied accordingly.

Water depth was 3 to 5 cm at application time and was maintained at that depth with no drainage for 3 days following application. After that, it was changed to the farmer's water management practice. Weed control and crop safety were evaluated by visual observations at regular intervals.

Herbicides evaluated in mixtures with butachlor were:

1. pyrazolate [4-(2, 4-dichloro benzoyl)-1, 3-dimethylpyrazol-5-y1-p-toluene-sulphonate]

2. naproanilide [-(B-naphthoxy) propionanilide]

3. chlomethoxynil [2.4-dichlorophenyl 1-4-nitro-3-methoxy phenyl ether]

4. bifenox (2, 4-dichlorophenyl-3-methoxy carbonyl-4-nitro phenyl ether)

5. oxadiazon [3-(2, 4-dichloro-5-isopropoxyphenyl)-5-tert-butyl-1, 3, 4-oxadiazole-2(3H)-one]

6. perfluidone [2-methyl-4-phenylsulphonyl trifluoromethylsulphoanilide]

RESULTS AND DISCUSSION

Preliminary studies were conducted in 1977 to select the best compounds to develop into mixtures with butachlor with *S. pygmaea* being the key target weed. All products were applied at their standard use rate 1 day after transplanting (DAT). Butachlor mixtures with pyrazolate and naproanilide provided excellent efficacy on *S. pygmaea* as well as other target weeds

(Table 3). The efficacy of these two mixtures was almost the same as the standard systematic treatment of butachlor applied at 1 DAT plus bentazone [3-isopropyl-1H-2, 1, 3-benzothiadiazine-(4)-3H-one-2, 2-dioxide] applied at 20 DAT. Only butachlor plus pyrazolate provided excellent control of *Potamogeton distinctus* A. Bennett.

Butachlor mixtures with chlomethoxynil, bifenox, oxadiazon and perfluidone provided improved control of *M. vaginalis*, *S. juncoides* and *Alisma canaliculatum* A. Br. & Bruche as compared to butachlor alone; however, control of *S. pygmaea* with these mixtures was unacceptable (less than 90% at 40 DAT). Based on these results, pyrazolate and naproanilide were selected as candidates for further development in mixtures with butachlor.

At four locations in 1978 and at seven locations in 1979, studies were conducted to determine the optimum ratio of butachlor plus pyrazolate and butachlor plus naproanilide. Compared with each product applied alone, all mixtures of butachlor/pyrazolate showed improved efficacy for a wide spectrum of target weeds (Tables 4, 5 and 6). A mixture of 0.75 a.i. kg/ha of butachlor plus 1.8 a.i. kg/ha of pyrazolate (half the standard use rate of each product alone) provided more than 90% control of all target perennial and annual weeds for more than 40 DAT, except for the colder area of Hokkaido where control of *S. pygmaea* was unstable (Table 4). Although the 0.75/1.8 ratio of butachlor/pyrazolate provided generally acceptable control, the 1.05/2.4 kg/ha ratio provided more stable efficacy on *S. juncoides* and S. pygmaea *in Hokkaido. Control of S. pygmaea* in Hokkaido was clearly rate responsive to pyrazolate but no mixture provided acceptable control of this species in Hokkaido.

No unacceptable crop injury was noted with any mixture of butachlor/pyrazolate under various soil conditions, water percolation loss rates, temperatures and rice seedling quality conditions.

In ratio studies with butachlor/naproanilide, butachlor at 0.75 kg/ha, regardless of the naproanilide rate, did not provide better than 90% control of *S. pygmaea* and was inconsistent in controlling *C. serotinus* and *Scirpus juncoides* (Table 5). The mixture of a ratio of at least 1.05 kg/ha of butachlor to 2.1 kg/ha of naproanilide was necessary to provide stable efficacy on a broad spectrum of target weeds. The efficacy difference between Hokkaido and other areas was not observed with this mixture.

Although it was not reflected in rice yields, treatments with naproanilide at higher rates applied alone and in mixtures resulted in early growth suppression of rice and the crop was slow to recover. Rice injury was more prevalent with higher rates of naproanilide, under sandy soil conditions and under high water percolation loss rates (Table 6). Unacceptable crop injury was not observed with loam or clay loam soils which normally have lower water percolation loss rates.

Table 3. Effects of butachlor mixed with various compounds on weed control and rice yield at three locations. Application was at 1 DAT.

Treatment	Herbicide rate	Weed control (%) (43-45 DAT) Annual weeds			Perennial weeds					Rice yield
		E.c.	M.v.	O.B.L.	E.a.	S.j.	S.p.	A.c	P.d.	
butachlor/pyrazolate	1.5 + 3.0	100	100	100	100	99	96	100	100	114
butachlor/naproanilide	1.5 + 3.0	100	100	100	100	100	98	100	17	108
butachlor/chlomethoxynil	1.5 + 2.1	100	100	100	100	97	76	100	12	105
butachlor/bifenox	1.5 + 2.1	100	100	100	100	99	57	100	0	104
butachlor/oxadiazon	1.5 + 0.6	100	100	100	100	99	57	100	0	104
butachlor/perfluidone	1.5 + 0.6	100	100	94	100	100	63	96	17	107
butachlor	1.5	100	91	97	98	91	43	86	0	102
pyrazolate	3.0	76	98	80	47	75	93	98	80	98
naproanilide	3.0	27	98	80	47	75	93	98	80	98
chlomethoxynil	2.1	52	99	99	60	29	55	60	25	100
bifenox	2.1	58	91	97	91	44	65	100	50	98
oxiadiazon	0.6	91	100	99	56	59	56	93	17	97
perfluidone	0.6	67	48	15	100	92	51	63	0	90
butachlor fb. bentazone	1.5 3.0	100	98	100	100	99	94	100	43	113
hand weeded check (twice)	—	93	24	59	88	92	74	94	100	100
Weedy check	—	0	0	0	-	0	0	0	0	77

Table 4. Effects of different mixtures of butachlor/pyrazolate on key problem paddy weeds and rice yield (1978)

Protocol		Control rate at 41-45 DA					
Chemicals	kg ai/ha	E.c. (%)	M.v. (%)	S.p. (%)	S.j. (%)	C.s. (%)	Rice (%)
butachlor/pyrazolate	0.75/1.8	99	98	100[2] (51)[3]	93	99	104
	0.75/2.4	100	100	98 (72)	95	100	105
	0.75/3.0	100	99	(100) (75)	94	99	105
	1.05/1.8	100	100	98 (58)	94	99	105
	1.05/2.4	100	100	100 (78)	99	100	104
	1.5/1.8	100	100	100	96	99	103
	1.5/3.0	100	100	98 (85)	98	97	102
	2.1/4.8	100	100	100 (87)	99	100	103
butachlor	0.75	99	84	35 (32)	80	79	98
	1.05	99	88	38 (34)	88	87	100
	1.5	99	93	36 (28)	92	90	98
pyrazolate	1.8	68	88	85 (60)	61	84	94
	2.4	78	91	95 (70)	73	90	97
	3.0	81	98	98 (85)	80	87	99
Weedy check	—	0	0	0	0	0	73
Hand weeded check	—	94	82	78	90	98	100

[1] *Values are means of 11 locations for 1978 and 1979.*

[2] *Values are means of 9 locations excluding Hokkaido.*

[3] *Values are for Hokkaido.*

Application timing studies with the recommended rates of butachlor/pyrazolate and butachlor/naproanilide were carried out in 1979 and 1980 at twelve locations (Tables 7 and 8). For these studies, the following formulated package mixture granules were used at 30 kg/ha of formulated product:

butachlor/pyrazolate mixture: 2.5% + 6% and 3.5% + 8%
butachlor/naproanilide mixture: 3.5% + 7%

Table 5. Effects of mixtures of butachlor/naproanilide on key problem weeds and rice growth (1978-1979). Values are means of 11 locations for 1979 and 1979 except in the first 3 rates of butachlor-naproanilide and butachlor at 0.75 kg/ha.

Protocol		Control rate at 41-46 DAT					Rate of rice growth & yield	
Chemicals	kg ai/ha	E.c. (%)	M.v. (%)	S.p. (%)	S.j. (%)	C.s. (%)	25-30 DAT (%)	Yield (%)
butachlor/naproanilide	0.75/1.5	92	96	53	83	81	97	99
	0.75/2.1	98	99	67	90	89	97	101
	0.75/3.0	98	100	88	94	86	92	101
	1.05/1.5	94	100	83	91	84	96	101
	1.05/2.1	98	99	95	95	94	96	102
	1.05/3.0	100	100	98	99	98	94	101
	1.5/3.0	99	99	97	99	96	91	101
	2.1/4.5	100	100	100	99	98	87	98
butachlor	0.75	96	84	28	85	82 95	98	
	1.05	99	88	36	88	87	94	100
	1.5	32	93	62	66	76	95	92
	2.1	36	57	91	70	60	92	94
	3.0	33	80	96	90	70	90	91
Weedy check	—	0	0	0	0	0	96	73
Hand weeded check	—	94	82	78	98	600 11	100	100

Table 6. Influence of butachlor/naproanilide and soil type on rice growth and yield (1978-1979)

Treatment	Herbicide rate (kg ai/ha)	Time of application (DAT)	Sandy soil[1] Rate of rice growth			Clay loam & loam soil[2] Rate of rice growth		
			25-30 DAT (%)	40-50 DAT (%)	Yield (%)	25-30 DAT (%)	40-50 DAT (%)	Yield (%)
butachlor/naproanilide	1.05/1.5	1-5	94	96	99	99	96	102
	1.05/2.1	"	95	97	102	98	98	104
	1.05/3.0	"	91	94	100	97	99	103
	1.5/3.0	"	86	93	99	96	98	103
	2.1/4.2	"	79	91	97	95	97	99
butachlor	1.05	"	94	96	98	97	96	98
	1.5	"	92	97	101	96	99	100
	2.1	"	88	95	99	91	97	99
naproanilide	1.5	"	93	91	93	97	93	92
	2.1	"	89	86	94	95	91	95
	3.0	"	87	86	92	94	89	91
	4.2	"	83	85	90	93	92	92
Hand weeded check	—	—	100	100	100	100	100	100

1: *Means of 6 locations with water percolation loss range of 1.5 to 2.5 cm/day.*

2: *Means of 5 locations with water percolation loss range of 0.5 to 1.5 cm/day.*

Table 7. Effect of time of application of selected mixtures of butachlor/ pyrozolate on key problem weeds and rice yield[1]. (1979-1980)

Protocol		Time of	Control rate at 40-46 DAT					Rice
Products	kg ai/ha	application	E.c. (%)	A.v. (%)	S.p. (%)	S.j. (%)	C.s. (%)	yield %)
butachlor/pyrazolate	0.75/1.8	3 DBT	92	87	82	75	93	105
		3 DAT	98	97	90	95	96	106
		7 DAT	94	97	90	93	94	104
		10 DAT	93	89	92	86	90	106
	1.05/2.4	3 DBT	95	94	90	89	94	104
		3 DAT	99	98	93	98	98	105
		7 DAT	97	100	95	96	96	107
		107 DAT	97	96	94	94	93	105
butachlor	1.5	3 DBT	98	87	26	81	91	99
		3 DAT	98	90	33	90	90	100
		7 DAT	98	69	34	89	88	97
		10 DAT	99	62	36	85	66	97
Weedy check	—	—	0	0	0	0	0	71

[1] : *Means of 12 locations fo 1979 and 1980.*

Table 8. Application time response of selected mixture ratio of butachlor/ naproanilide on key problem weeds and rice yield (1979-1980) [1,2]

Protocol		Time of	Control rate at 40-46 DAT					Rice
Products	kg ai/ha	application	E.c. (%)	A.v. (%)	S.p. (%)	S.j. (%)	C.s. (%)	yield (%)
		(DAT)						
butachlor/naproanilide	1.05/2.1	3	99	96	91	97	96	104
		7	97	90	93	98	96	103
		10	95	96	96	91	86	103
butachlor	1.5	3	99	88	29	88	88	100
		7	98	73	17	87	88	98
		10	97	73	32	82	76	98
Weedy check	—	—	0	0	0	0	0	67

[1] : *Values presented are mean of 8 locations for two-year trials in 1979 and 1980.*

[2] : *Rate of rice yield were presented to the butachlor 15 kg ai/ha at 3 DAT application.*

In these application timing studies, both mixtures again demonstrated improved efficacy on the target perennial and annual weeds, and the flexibility of the time of application could be expanded compared to butachlor alone.

As compared with butachlor alone at 1.5 kg/ha, the mixture of butachlor/pyrazolate provided expanded application timing for control of *M. vaginalis*, *S. juncoides* and *C. serotinus* as well as good control of *S. pygmaea*. With the mixture of 0.75/1.8 kg/ha, the best application timing was at 3 to 7 DAT. Application at 3 days before transplanting (DBT) provided reduced efficacy, especially on *M. vaginalis*, *S. pygmaea* and *S. juncoides*, due to machine transplanting and water management practices, and application at 10 DAT also showed the same unstable efficacy on *M. vaginalis*, *S. juncoides*, and *C. serotinus*. A mixture of 1.05/2.4 kg/ha, could be applied from 3 DBT to 10 DAT although its efficacy was slightly unstable for *S. pygmaea* and *S. juncoides* control. These was no crop safety problem at any application timing with either mixture (Table 7).

The butachlor/naproanilide mixture was evaluated only as a post-transplanting application crop injury because it is not practical for use before transplanting due to the possibility of as determined previously.

The results were similar to those for butachlor/pyrazolate, and the best time of application was 3 to 7 DAT. Efficacy on *S. juncoides* and *C. serotinus* was reduced at 10 DAT. But for *S. pygmaea* control this mixture showed better effect at later application times. There was no crop suppression observed with this mixture at any application time (Table 8).

In 1981, comparison tests between butachlor mixed with pyrazolate and naproanilide and the systematic application of butachlor followed by thobencarb/simetryne/MCPB, which is widely used in Japan, were carried out in large scale plots at seven locations (Table 9).

Both mixtures provided long lasting efficacy on all target perennial and annual weeds, and their efficacy was much higher than that of the systematic application especially in *S. pygmaea* and *Cyperus serotinus* control. The lasting efficacy of the butachlor/naproanilide mixture on *S. pygmaea* and *C. serotinus* was less than that of the butachlor/pyrazolate mixture.

Table 9. Comparison of effects between butachlor mixed with pyrazolate and naproanilide, and the current systematic application system on weeds and yield (1981).

Protocol			Control rate on key problem weeds[1]										
			E.c.		M. v.		S.p.		S.j.		C.s.		
Products	kg ai/ha	Timing	A	B	A	B	A	B	A	B	A A	B	Yield
butachlor/prazolate	0.75/1.8	6 DAT	99	98	95	93	90	90	93	91	90	91	103
	1.0/2.4	6 DAT	100	98	99	97	90	87	98	97	90	94	101
butachlor/naproanilide	1.05/2.1	6 DAT	98	95	88	87	88	64	97	95	91	79	100
butachlor fb.	1.5 fb.	6 DAT fb	100	98	100	98	53	68	96	92	84	74	100
	3/0.45/0.28	20 DAT											

[1] : *Means of seven locations.*

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INTEGRATION OF CULTURAL MANAGEMENT AND CHEMICAL CONTROL OF WEEDS IN BROADCAST-SEEDED FLOODED RICE

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ABSTRACT

Despite puddling, weeds are more difficult to control in broadcast-seeded flooded rice (*Oryza sativa* L.) than in transplanted rice, so other weed control measures must be developed and improved.

Through experiments conducted 1976-83 at the International Rice Research Institute (IRRI) and at the Philippine Bureau of Plant Industry (BPI) stations in Maligaya, Bicol, and Visayas the effects of herbicides and their integration with cultural practices, such as tillage and water depth, on weed control in broadcast-seeded flooded rice were studied.

Degree of tillage did not affect weed biomass and grain yield. Regardless of tillage level, thiobencarb (S-4-chlorobenzyl diethylthiocarbamate)/2, 4-D (2, 4-dichlorophenoxy acetic acid) produced grain yield significantly higher than that of the untreated check.

Water depth did not affect weed biomass and grain yield. Thiobencarb/2, 4-D also did not affect weed biomass, but significantly increased grain yield under both water depths.

All herbicides used in the advanced screening trials generally gave significantly higher yield than the untreated control at IRRI and the BPI stations. Thiobencarb/2, 4-D and butachlor (N-butoxymethyl-α-chloro-2', 6'-diethylacetanilide) + 2, 4-D were occasionally toxic to rice.

For control of *Scirpus maritimus* L., bentazon [3-isopropyl-(1H)-benzo-2, 1, 3-thiadiazin-4-one 2, 2-dioxide] and 2, 4-D or their combination were highly effective and completely safe to broadcast-seeded rice and resulted in significant grain yield increases.

Alternative weed control technology is developed and is being modified for broadcast-seeded flooded rice. The final choice of these alternatives would depend largely on the weed situation, and on farmers' management capabilities, economic resources, and returns from investments.

INTRODUCTION

Most rice in tropical Asia is established by the transplanting methiod, which is time-consuming, laborious, and costly. In many developed countries where labor supply is limited and labor cost is high, the more efficient practice of planting rice by direct seeding has been adopted (Smith and Shaw, 1966). This method is faster and easier, and grain yields are similar with and occasionally higher than those obtained with transplanting (IRRI, 1967; De Datta, 1981).

One method of direct seeding is broadcasting pregerminated seeds onto puddled soil. This technology, which can be practiced in areas where irrigation water is available is not actually new. It is done in parts of India, Bangladesh, Sri Lanka, and the Philippines (De Datta, 1981). But even with the introduction of modern rice cultivars and associated technology, the adoption of broadcast seeding has not been fast and widespread enough because certain problems are associated with its practice.

In the past, the most important reason for the rather slow adoption of direct seeding, particularly broadcast seeding in Southeast Asia, is weed control. Weed infestation is more critical in broadcast-seeded rice because the land is exposed during the initial growth stage till the rice seedlings grow and the vegetation closes in (Moorthy and Dubey, 1979). Weed competition for about 6 weeks in broadcast-seeded rice could result in significant grain yield reductions (Dubey et al., 1977); hence, weed control should be done during the early period of competition. At such time, however, the rice seedlings are difficult to distinguish from the grassy weed seedlings. Moreover, hand weeding in broadcast-seeded rice is arduous because laborers cannot move through the fields without destroying some rice plants (De Datta and Bernasor, 1973; Chang and De Datta, 1974; Ali and Sankaran, 1975; Subiah and Morachan, 1976).

Various weed control techniques, such as tillage intensity, water management, and herbicide use or their integration, have been shown to affect directly or indirectly the degree of weed control achieved in broadcast-seeded flooded rice.

In the Philippines, Malaysia, and Thailand, broadcast-seeded areas are rapidly increasing particularly in the dry season when water control from irrigation is good. Current modern rice cultivars also are of shorter duration than cultivar IR8, which allows intensive croppings even with broadcast seeding.

Our paper summarizes recent results on the effects of various control measures on the level of weed infestation and grain yield of broadcast-seeded flooded rice.

REVIEW OF LITERATURE

Weed infestation in broadcast-seeded flooded rice can be minimized by thorough tillage, good water control, and use of herbicides.

Tillage degree

An obvious benefit of tillage is suppression of weed growth. Puddling, the major method of land preparation in Asia, reduces the number of weeds, compared with non-puddled condition (De Datta, 1977b; Moody and De Dataa, 1977; Reddy and Hukkeri, 1979). Land preparation for puddling of a lowland rice soil consists of plowing and harrowing. Conventional land preparation for effective weed control normally requires one plowing and at least two harrowings.

Results from previous studies indicated that increasing tillage intensity beyond the conventional further decreases weed incidence. After a series o of experiments using different degrees of tillage for land preparation, Curfs (1975) noted that weeds were suppressed well and the grain yields obtained were relatively higher as tillage was intensified. Elias (1969) reported on rice farmers' claims that rice grain yield increased with increasing number of cultivations for land preparation. Results from an experiment showed that as the number of passes of harrowing was increased from two to five, weed incidence decreased and grain yield increased (IRRI, 1967). However, Vargas (1978) observed that beyond one plowing followed by two harrowings, dry weed weight and grain yield were not significantly affected.

Kuipers (1975) considered tillage as most important where chemical weed control is not practiced. Manuel et al. (1979) reported that herbicides did not give any additional yield advantage when land preparation was thorough. Even the perennial weed *Paspalum distichum* L. was substantially reduced when the field received one plowing followed by 2-3 harrowings (Diop, 1982).

However, even with good management such as thorough land preparation, herbicides are often necessary for high yields in broadcast-seeded flooded rice (Vargas, 1978). Broadcast-seeded flooded rice significantly outyielded transplanted rice when optimum land preparation was followed by chemical weed control (IRRI, 1971). Tyan (1979) reported that tillage alone provided only 52% weed control, but control increased to 97% when tillage was combined with postplanting application of a herbicide.

Water management

One important reason for submerging a rice field is its effect on weed control (Williams, 1969). Flooding can be continuous, intermittent, or deep. Several workers suggested that deep flooding eliminates weeds (Moomaw et al., 1966; Oelke, 1969).

The nature of weed growth and extent of weed control have been observed to vary with flooding depth. Under shallow continuous flooding (2.5 cm) there were more sedges than broadleaf weeds and grasses, and in 15 cm of standing water grasses and sedges were practically suppressed (De Datta et al., 1973). Mabbayad (1967) noted that *Monochoria vaginalis* (Burm. f.) Presl was the major weed in deep water while at zero water depth (soil saturation), *Echinochloa* spp. and *Fimbristylis miliacea* (L.) Vahl were predominant.

Evidence in literature has shown that shallow (less than 2.5 cm) continuous flooding contributes to weed growth and increases labor cost for weeding (Ghose et al., 1960; Chang, 1965; Mohan, 1965; Singh and Singh, 1966). On the other hand, Chandler (1966) reported that beyond 15 cm of standing water, some harmful effects may develop and deep water makes management practices difficult.

Results of experiments at IRRI showed that the best yields from direct seeding were attained with water depths ranging between 7.5 and 12.5 cm during the wet season and between 2.5 and 7.5 cm during the dry season (De Datta et al., 1973).

Vargas (1978) observed that increasing depth of continuous flooding from 2.5 to 7.5 cm increased grain yields of broadcast-seeded rice when no weed control was adopted. No differences in grain yield were found between chemical weed control with 2.5 cm of standing water and untreated plots with 7.5 cm water. Mabbayad (1967), however, reported that even at a shallow water depth of 2.5 cm, weed weight already decreased markedly.

Chemical weed control

Since hand weeding is difficult to do in broadcast-seeded flooded rice, the use of herbicides maybe the best direct weed control method.

Control of annual weeds. Propanil (3', 4'-dichloropropionanilide) and molinate (S-ethyl N N-hexamethylenethiocarbamate) were the first selective herbicides developed to control grassy weeds in rice and are widely used in Europe, South America, and the United States (Smith and Shaw, 1966). In the United States, propanil and molinate are used extensively in drill-seeded and water-seeded rice (Smith, 1977). These herbicides, however, are not popularly used in the Asian tropics because of their prohibitive cost and erratic effects.

Continuous herbicide screening trials at IRRI have shown that granular formulations of butachlor, thiobencarb, piperophos (S-2-methyl-piperidinocarbonyl methyl O, O-dipropyl phosphorodithioate)/dimethametryn [2-(1, 2-dimethylpropylamino)-4-ethylamino-6-methylthio-1, 3, 5-triazine], and butralin [4-(1, 1-dimethylethyl)-N-(l-methylpropyl)-2, 6-dinitrobenzene amine] were highly effective and selective in controlling barnyard grass and other weeds under tropical conditions (De Datta and Bernasor, 1971, 1973; De Datta, 1979). Among them, butachlor and thiobencarb are perhaps the most widely tested in direct-seeded rice. More herbicides were identified: X052 (2, 4-dichlorophenyl 3-methoxy-4-nitrophenyl ether)/2, 4-D IPE, MT-101 [α -(B-naphthoxy) propionanilide], and NTN 5810 (4-methylthio-3, 5-xylyl methlcarbamate) + 2, 4-D. They adequately controlled the predominant lowland rice weed species such as *Echinochloa* spp., *M. vaginalis*, and *Cyperus difformis* L. (De Datta, 1977b).

More recently, naproanilide (code named MT-101)/thiobencarb, piperophos/2, 4-D, thiobencarb/2, 4-D, bifenox [methyl 5-(2, 4-dichlorophenoxy)-2-nitrobenzoate)/2, 4-D, and butachlor + 2, 4-D continued to look promising for control of weeds in broadcast-seeded lowland rice at IRRI and at 3 Philippine BPI stations.

Control of Scirpus maritimus. It has been suggested that continuous application of the same or identical herbicides for control of annual weeds would cause a shift to the more difficult-to-control perennial weeds such as *S. maritimus* (Vega et al., 1971; De Datta, 1977a).

S. maritimus has increasingly become one of the serious problems in lowland rice fields in several countries in Africa, Europe, and east and tropical Asia (De Datta, 1974; De Datta and Lacsina, 1974; Bernasor, 1983). It multiplies rapidly and is highly competitive. Results from studies showed yield reductions of 50 to 100% due to whole season competition.

Among the effective control measures for season-long control of *S. maritimus* in a rice crop is the use of herbicides. Fenoprop [(±)-2-(2, 4, 5-trichlorophenoxy) propionic acid] was the first herbicide found effective against the weed in direct-seeded rice (Chiapparini, 1963; Piacco, 1963; Tinarelli and Tina relli, 1963; Montessori, 1964; Arcuset and Pecheur, 1967). In experiments at IRRI, fenoprop, MCPP [(±)-2-(4-chloro-2-methylphenoxy) propionic acid], and bentazon applied 26 days after seeding (DS) provided reasonable control of *S. maritimus* in broadcast rice, resulting in significant grain yield increases from these treatments over the untreated control (De Datta and Lacsina, 1974).

Other chemicals, such as propanil and 2, 4-D, have shown foliar activity on *S. maritimus* when applied singly or in combination in transplanted rice (Paller et al., 1971; Bernasor et al., 1979). Together with bentazon, they were examined for control of the weed in broadcast-seeded rice. The results are summarized in this paper.

MATERIALS AND METHODS

Experiments were conducted at the experimental farm of IRRI, Los Baños, Laguna, and the BPI stations at Maligaya, Bicol, and Visayas. The results with some selected treatments of identical studies were subjected to a combined analysis across crop seasons or years. Some chemical and physical soil properties of the experimental sites are presented in Table 1.

Table 1. Chemical and physical properties of lowland soils at IRRI and 3 Bureau of Plant Industry experiment stations.

Property	IRRI	Maligaya	Bicol	Visayas
pH 2/v H_2O (1/1)	6.6	6.1	4.6	6.6
Organic C (%)	1.66	1.47	2.12	1.76
Total N (%)	0.20	0.11	0.20	0.14
Available P (ppm)	1.5	5.7	19	39
Exchangeable K (meq./100 g)	1.47	0.09	0.09	0.58
CEC (meq./100 g)	28	32	36	54
Soil type	Maahas clay clay	Maligaya silty clay loam	Pili clay	Sta. Rita clay
Soil order	Alfisol	Alfisol	Vertisol	Vertisol

Experiment 1. Effects of degree of Tillage on Weed Control in Broadcast-seeded Flooded Rice

Three experiments were conducted at IRRI using a split-plot design with 3 replications on 18-24 m^2 plots.

Treatments. Three tillage levels were used on the main plots — one plowing followed by one harrowing, one plowing followed by two harrowings, and one plowing followed by three harrowings. The mold-board plow and comb-toothed harrow were used in the tillage operations. Each harrowing was equal to three passes of the implement. Planting was done at the same time.

On the subplots two weed control treatments were compared: thiobencarb/2, 4-D applied at 1.0 kg/ha 6-8 DAS and untreated control.

Planting. Pregerminated seeds of IR36 were broadcast at the rate of 100 kg/ha onto the puddled field. The field was kept saturated until application of the herbicide, and thereafter continuously flooded to at least 5 cm until harvest.

Fertilizer application. Seventeen kg of P as superphosphate, and 33 kg K/ha as muriate of potash were broadcast and incorporated with the last pass for harrowing. Nitrogen as ammonium sulfate was applied at the rate of 90 kg N/ha in 3 equal split doses: at 15 days after planting, at maximum tillering, and at panicle initiation.

Experiment 2. Effects of Water Depth on Weed Control in Broadcast-seeded Flooded Rice

Treatments. On the main plots 2 water depths were used: 2.5 cm and 7.5 cm standing water. Just before herbicide application, the plots were flooded according to the treatments and were maintained at those levels until harvest. Each plot had individual levees, and metersticks at the inlet and drainage points monitored the desired depth.

On the subplots two weed control treatments were compared: thiobencarb/2, 4-D applied at 1.0 kg/ha 7-8 DAS and untreated control.

Planting. Pregerminated seeds of IR36 were broadcast onto leveled plots at the rate of 100 kg/ha. The field was kept saturated until application of the herbicide.

Fertilizer application. Seventeen kg P/ha as superphosphate and 33 kg K/ha as muriate of potash were broadcast and incorporated with the soil at final harrowing. Nitrogen as ammonium sulfate was applied at 90 kg N/ha in 3 equal splits: 15 days after planting, at maximum tillering, and at panicle initiation.

Experiment 3. Chemical Control of Annual Weeds in Broadcast-seeded Flooded Rice

Location. Advanced herbicide trials in broadcast-seeded flooded rice continued at IRRI and the BPI stations at Maligaya, Bicol, and Visayas from 1978 to 1982 dry (except at Visayas) and wet seasons. The 1979 and 1982 wet seasons crops at IRRI and the 1978 dry and wet season crops at Maligaya failed due to typhoons. At all locations, IR42 was used from 1978 to 1979, and IR36 from 1979 on.

The experiments were conducted in a randomized complete block design with 4 replications and a plot size of 15 m^2.

Treatments. The herbicide treatments included bifenox/2, 4-D EE, naproanilide/thiobencarb, piperophos/2, 4-D IPE, thiobencarb/2, 4-D IPE, butachlor + 2, 4-D IPE, and an untreated check. The chemicals were applied 6-8 DS.

Planting. Pregerminated rice seeds were broadcast at the rate of 80 kg/ha onto puddled and leveled plots with individual levees. Seeds of *Echinochloa* spp. at the rate of 2-3 kg/ha were broadcast on all plots to ensure uniform weed stand.

Fertilizer application. At IRRI, nitrogen as ammonium sulfate was applied at the rate of 80 and 60 kg N/ha in the dry and wet seasons, respectively, in 2 split doses: 2/3 was incorporated with the soil at final harrowing and 1/3 at 5-7 days before panicle initiation (DBPI). Fertilizer applications at the BPI stations were made according to initial soil fertility.

Water management. The plots were kept saturated until application of the herbicides. Immediately before application, the plots were flooded 2-3 cm deep. The water depth was raised to at least 5 cm one week after herbicide application and maintained at that level until crop. maturity.

Exper nent 4. Chemical Control of the Per nnial Sedge *Scirpus maritimus*

Two experiments were conducted using the randomized complete block design with 4 replications and a plot size of 15 m^2.

Treatments. The treatments were bentazon applied at 1.0 kg/ha, 2, 4-D at 0.75 kg/ha, bentazon + 2, 4-D at 0.5 kg/ha, propanil + 2, 4-D at 1.5 + 0.5 kg/ha, and the untreated check. The herbicides were sprayed at 25 DAS (*S. maritimus* had 6-8 leaves). Granular butachlor was applied to all plots at 1.0 kg/ha DAS to control the annual weeds.

Planting. Pregerminated seeds of IR36 were broadcast at the rate of 80 kg/ha onto puddled, leveled plots.

Fertilizer application. Nitrogen as ammonium sulfate was added at the rate of 80 kg N/ha in two split doses: 2/3 was incorporated with the soil at final harrowing and 1/3 at 5-7 DBPI.

Water management. The plots were kept saturated for 5 DAS, then flooded at least 5 cm deep until harvest.

Disease and pest control. Protective measures against diseases and pests such as insects, rats, and birds were provided at maximum level to all experiments.

Data taken

Weed biomass. At flowering of the grassy weeds (in Experiments 1 and 2) or at near senescence of *S. maritimus* (in Experiment 4), the weeds present in the quadrat 50 x 50 cm were cut at the base, dried to a constant weight, and then weighed. Two quadrat samples per plot were taken.

Grain yield. Grain yield samples were taken from 5 m^2 at the center of the plot. The grain weight was adjusted to 14% moisture and expressed in tons per hectare (t/ha).

RESULTS AND DISCUSSION

In Experiment 1, the weed species present in the area prior to the experiment were *Cyperus iria* L., *Leptochloa chinensis* (l) Nees, *M. vaginalis*, *C. difformis*, *Echinochloa* spp., and *P. distichum*.

Weed biomass

Biomass as weed control index was not significantly affected by the tillage intensity (Table 2). However, regardless of the tillage level used, application of thiobencarb/2, 4-D resulted in about 50% biomass reduction, which was significant in plots that received 2 harrowings. Also, weed biomass in the untreated plots did not drecrease with increasing tillage intensity. For example, biomass was higher in plots that were harrowed twice than in plots that were harrowed once. But the lowest biomass was observed in plots that were harrowed thrice.

Table 2. Weed biomass as affected by tillage level and weed control treatment in broadcast-seeded flooded IR36 rice at IRRI. (av. of the 1976 dry and 1977 dry and wet season croppings). In a column, means followed by a common letter are not significantly different at the 5% level of DMRT. fb = followed by.

Tillage level	Weed Biomass (g/m^2)		
	Thiobencarb/2, 4-D	Untreated	Difference
One plowing fb one harrowing	69 a	158 a	89^{ns}
One plowing fb two harrowings	72 a	179 a	107*
One plowing fb three harrowings	79 a	141 a	62^{ns}

**Significant at 5% level.*
ns = not significant.

Grain yield

Degrees of tillage did not affect grain yeild (Table 3). However, differences were significant between the herbicide-treated and the untreated plots which received one and three harrowings, and highly significant between the treated and the untreated plots that were harrowed two times.

The results indicate that although biomass was not affected by the application of thiobencarb/2, 4-D, grain yield was significantly increased by the herbicide treatment. Hence, the nonsignificant 50% weed control with herbicide was adequate to cause substantial yield increase.

Table 3. Grain yield of broadcast-seeded flooded IR36 rice as affected by tillage level and weed control treatment at IRRI. (av. of the 1976 dry and 1977 dry and wet season croppings). In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. fb = followed by

Tillage level	Grain Yield (t/ha) Thiobencarb/2, 4-D	Untreated	Difference
One plowing fb one harrowing	5.2 a	3.9 a	1.3*
One plowing fb two harrowings	5.3 a	3.3 a	2.0**
One plowing fb three harrowings	5.0 a	4.1 a	0.9*

**Significant at 5% level.*
***Significant at 1% level.*

Neither weed biomass nor grain yield was markedly affected by degree of land preparation. These results seem to contradict earlier findings that weed incidence decreases and grain yield increases as tillage degree is intensified (IRRI, 1967; Elias, 1969; Curfs, 1975), but agree with other findings that even with good land preparation herbicides are still necessary to improve weed control (Tyan, 1979) and increase grain yields in broadcast-seeded flooded rice (Vargas, 1978).

Results further agree with previous reports that one plowing and one harrowing in puddled fields was sufficient to bring down weed infestation (De Datta, 1977a, Moody and De Datta, 1977, Reddy and Hukkeri, 1979).

In Experiment 2, the major weed species were *M. vaginalis*, *F. miliacea*, *C. difformis*, *C. iria*, *Echinochloa* spp., and *L. chinensis*.

Weed biomass

Neither water depth nor weed control affected weed biomass (Table 4). However, the reduction in biomass was about 3 times larger in the untreated than in the treated plots when the water depth was raised from 2.5 cm to 7.5 cm. In contrast, the difference between the treated and the untreated was greater at 2.5 than at 7.5 cm. The results suggest that in situations where herbicide is used, shallow flooding is adequate, but where herbicide is not applied deep flooding becomes necessary to minimize weed growth in broadcast-seeded flooded rice.

Grain yield

Yield was significantly increased by herbicide application, regardless of water depth (Table 5). The difference between the treated and the untreated plots was highly significant at 2.5 cm. On the other hand, water depth did not affect grain yield in either weed control treatment. Without weed control, however, grain yield was slightly higher at 7.5 cm than at 2.5 cm.

Table 4. Weed biomass as affected by water depth and weed control treatment in broadcast-seeded flooded IR36 rice at IRRI (av. of the 1976 wet and 1977 dry and wet season croppings).

Water depth (cm)	Weed Biomass (g/m^2) Thiobencarb/2, 4-D	Untreated	Difference
2.5	67	185	118^{ns}
7.5	44	121	77^{ns}
Difference	23^{ns}	64^{ns}	

ns = not significant.

Table 5. Grain yield of broadcast-seeded flooded IR36 rice as affected by water depth and weed control treatment at IRRI (av. of the 1976 wet and 1977 dry and wet season croppings).

Water depth (cm)	Yield (t/ha) Thiobencarb/2, 4-D	Untreated	Difference
2.5	5.6	2.9	2.7**
7.5	5.5	3.8	1.7*
Difference	0.1^{ns}	0.9^{ns}	

**Significant at 5% level.*
***Significant at 1% level.*
ns = not significant.

Water depth of 7.5 cm gave less biomass than 2.5 cm, but the difference was not pronounced. This confirms previous findings (Williams, 1969; De Datta et al., 1973). Although the application of thiobencarb/2, 4-D did not adequately control weeds, it resulted in significant grain yield increases in both water depths but which were slightly higher at 2.5 cm. This result somewhat contradicts the finding of Vargas (1978) that application of a herbicide did not increase grain yield at 7.5 cm water depth.

The principal weeds at IRRI, Maligaya, Bicol, and Visayas in Experiment 3 were *Echinochloa glabrescens* Munro ex Hook.f., *E. crus-galli* ssp. *hispidula* (Retz.) Honda, *C. difformis*, and *M. vaginalis. Sphenoclea zeylanica Gaertn. was common in Bicol; growth of S. maritimus* at IRRI was patchy.

Grain yield

During the dry season, the average yield increase due to herbicide application ranged from 1.7 t/ha with bifenox/2, 4-D to 2.5 t/ha with naproanilide/thiobencarb in all locations (Table 6). The differences in grain yield between the herbicide treatments and the untreated control were significant at IRRI, Maligaya, and across the averages of the three sites (IRRI, Maligaya, and Bicol). At Bicol, however, the yield with butachlor + 2, 4-D was similar to that of the untreated check and significantly lower than the yield with naproanilide/thiobencarb.

Table 6. Effect of herbicides applied 6-8 days after seeding on grain yield of broadcast seeded flooded rice (IR36 and IR42) at IRRI, and the Philippine Bureau of Plant Industry experiment stations at Maligaya and Bicol during the dry season (av. of 5 years, 1978-1982). In a column, means followed by a common letter are not significantly different at the 5% level by DMRT.

Treatment	Rate (kg/ha)	Yield (t/ha) IRRI	Maligaya (4 years)	Bicol	Mean
Naproanilide/thiobencarb	1.0/0.7	4.9 a	4.6 a	5.4 a	5.0 a
Piperophos/2, 4-D IPE	0.33/0.17	4.3 a	4.8 a	4.7 ab	4.6 a
Thiobencarb/2, 4-D IPE	1.0/0.5	4.6 a	4.2 a	4.5 ab	4.4 a
Butachlor 3 2, 4-D IPE	0.75 + 0.5	4.4 a	4.8 a	3.6 bc	4.3 a
Bifenox/2, 4-D EE	2.0/0.66	4.6 a	3.6 a	4.4 ab	4.2 a
Untreated check	—	2.6 b	2.3 b	2.5 c	2.5 b

1/ = the herbicides were applied proprietary mixtures
IPE = isopropyl ester.
+ = the herbicides were applied one after the other.
EE = ethyl ester.

During the wet season, the yield increase in the herbicide treatments over the untreated plot across all locations was only about 1.5 t/ha (Table 7). All the herbicides gave significantly higher yields than the untreated control at IRRI, Maligaya, and Bicol. At Visayas, the yields with naproanilide/thiobencarb, piperophos/2, 4-D, and butachlor + 2, 4-D were similar to the yield of the untreated check. However, grain yields among herbicide treatments did not differ at Visayas, as well as at IRRI and Bicol. At Maligaya, bifenox/2, 4-D and butachlor/2, 4-D gave yields significantly less than the yield with piperophos/2, 4-D.

The results show that all herbicides were effective in controlling weeds and increased the grain yield of broadcast-seeded flooded rice in some locations. The grain yield increases were more consistent in the dry than in the wet season. Butachlor and thiobencarb, which were earlier reported as highly selective on broadcast-seeded flooded rice (De Datta and Bernasor, 1971, 1973; De Datta, 1977b), were occasionally moderately toxic to the crop when combined with 2, 4-D. This was usually observed when the plots had too much water or when days were somewhat cool at application time. However, the rice plants always recovered from the herbicide injury.

Table 7. Effect of herbicides applied 6-8 days after seeding on grain yield of broadcast-seeded flooded rice (IR36 and IR42) at IRRI, and the Philippine Bureau of Plant Industry experiment stations at Maligaya, Bicol, and Visayas during the wet seasona (av. of 5 years, 1978-1982).

Treatment	Rate (kg a.i.[c]/ha)	Yield (t/ha) IRRI[d]	Maligaya[e]	Bicol	Visayas	Mean
Thiobencarb/2, 4-D	1.0/0.5	2.5 a	4.6 abc	4.3 a	4.1 a	4.0
Naproanilide/thiobencarb	1.0/0.7	2.2 a	4.9 ab	3.9 a	4.0 ab	3.9
Piperophos/2, 4-D IPE	0.33/0.17	2.2 a	5.2 a	3.6 a	3.9 ab	3.9
Bifenox/2, 4-D EE	2.0/0.66	2.7 a	4.1 c	3.7 a	4.3 ab	3.8
Butachlor + 2, 4-D IPE	0.75 + 0.5	2.6 a	4.3 bc	4.0 a	4.0 ab	3.8
Untreated check	—	1.2 b	2.4 d	2.5 b	3.3 b	2.5

[a]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. b/ = the herbicides were applied as proprietary mixtures. IPE = isopropyl ester. EE = ethyl ester. + = the herbicides were applied one after the other. [c]Active ingredient. [d]Av. of 3 years. [e]Av. of 4 years.

In Experiment 4, *S. maritimus* infestation in the experimental area was almost 100%.

Weed biomass

All the herbicides, except 2, 4-D, significanlty reduced weed biomass (Table 8). Herbicide combination controlled the weed slightly better than the single application did. For example, the combination bentazon + 2, 4-D gave 91% weed control as against 77 and 64% provided by single applications of bentazon and 2, 4-D, respectively. Propanil + 2, 4-D also provided better weed control, but was moderately toxic to rice.

Table 8. Biomass of **S. maritimus** *as affected by herbicides applied at 25 days after seeding of broadcast-seeded flooded IR36 rice at IRRI (av. of 1982 wet and 1983 dry season croppings). Means followed by a common letter are not significantly different at the 5% level by DMRT.*

Treatment	Rate (kg/ha)	Biomass (g/m^2)
Bentazon + 2, 4-D	0.5 + 0.5	17 a
Propanil + 2, 4-D	1.5 + 0.5	38 a
Bentazon	1.0	44 a
2, 4-D	0.75	69 ab
Untreated check	—	194 b

+ = the chemicals were tank-mixed.

Grain yield

All treatments gave significantly more yield than the untreated control (Table 9). Bentazon + 2, 4-D produced the highest grain yield (4.0 t/ha), which was one ton higher than the yield with propanil + 2, 4-D. A single application each of bentazon and 2, 4-D also gave slightly higher grain yield than that with propanil + 2, 4-D.

Table 9. Grain yield of broadcast-seeded IR36 rice as affected by herbicides applied at 25 days after seeding at IRRI (av. of 1982 wet and 1983 dry season croppings). Means followed by a common letter are not significantly different at the 5% level by DMRT.

Treatment	Rate (kg / ha)	Yield (t/ha)
Bentazon + 2, 4-D (tank-mix)	0.5 + 0.5	4.0 a
2, 4-D	0.75	3.7 a
Bentazon	1.0	3.6 a
Propanil + 2, 4-D (tank-mix)	1.5 + 0.5	3.0 a
Untreated check	—	1.8 b

Bentazon, propanil, and 2, 4-D, which were effective for *S. maritimus* control in transplanted rice (Paller et al., 1971; De Datta and Lacsina, 1974; Bernasor et al., 1979), were found equally effective and, except for propanil + 2, 4-D, highly selective in broadcast-seeded flooded rice. They resulted in substantial grain yield increases. Grain yields between combined and single applications of herbicides did not differ, indicating that herbicide mixtures are not necessary in single-weed vegetation situations.

SUMMARY AND CONCLUSION

Experiments at the IRRI farm and at the BPI stations at Maligaya, Bicol, and Visayas from 1976 to 1983 studied the effect of herbicides and their integration with some cultural practices such as degree of tillage and water depth, on weed control in broadcast-seeded flooded rice. Selected treatments from two or more identical studies were subjected to a combined analysis and presented as one experiment.

The first experiment summarizes three trials conducted at IRRI during the 1976 dry season and the 1977 dry and wet seasons. Three degrees of tillage were evaluated and chemical weed control was compared with the untreated check.

Neither weed biomass nor grain yield was affected by degrees of tillage. Thiobencarb/2,4-D slightly reduced weed growth and significantly increased grain yield regardless of tillage.

The second experiment summarizes the results of three studies conducted at IRRI during the 1976 wet season and the 1977 dry and wet seasons. Two water depths were used and the same chemical weed control was compared with the untreated control.

Without weed control, water depth of 7.5 cm gave less weed biomass and higher grain yield than 2.5 cm but the difference was not significant. Thiobencarb/2,4-D slightly affected control of weeds, but significantly increased grain yields in both water depths.

The third experiment was conducted at IRRI and three BPI stations from 1978 to 1982 dry and wet seasons. Five herbicides were compared with the untreated check.

Naproanilide/thiobencarb, thiobencarb/2,4-D, piperophos/2,4-D, bifenox/2,4-D, and butachlor + 2,4-D provided effective weed control and most often gave significant yield increases over the untreated control at IRRI, Maligaya, Bicol, and Visayas, Thiobencarb/2,4-D and butachlor + 2,4-D occasionally caused temporary crop injury.

The fourth experiment summarizes the results of studies conducted at IRRI during the 1982 wet season and 1983 dry season. Four herbicides and herbicide combinations were evaluated for control of the perennial sedge *S. maritimus* and compared with the untreated control.

Bentazon and 2,4-D, either singly or in combination, provided adequate control of *S. maritimus.* They were completely safe to broadcast-seeded lowland rice, and produced significantly higher yields than the untreated check. Propanil + 2,4-D was likewise effective in controlling the weed but was moderately toxic to the crop.

Several studies have indicated that the more thorough the land preparation, the fewer the weeds. However, the economics of thorough land preparation and the degree of weed control achieved should be equated with labor and time savings for postplanting weed control operations.

Good water management will minimize weed infestation, thereby reducing the need for other weed control measures including the use of herbicides. But, in situations where good water control is not available, hberbicides can be the major factor for postseeding weed control. Thorough herbicide field testing is necessary, however, as responses of weeds and the rice crop to specific herbicides vary with changes in other factors such as soil and moisture conditions.

Integration of weed control practices would cut down weed control problems, but must be exercised judiciously to be economical and relevant at the farm level.

As a result of new weed control technology with good irrigation and shorter maturing rices, many farmers in the Philippines, Malaysia, and Thailand are switching from transplanting to broadcast seeding onto puddled fields. Increased labor cost also encourages farmers to adopt broadcast seeding.

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EFFECTIVE METHODS OF WEED CONTROL IN UPLAND RICE

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ABSTRACT

An investigation was undertaken during the wet season (June-July to October-November) of 1978 and 1979, to find out the effective method of weed control in upland rice.

The effect of tillage treatment on weed control in upland rice was moderate. Other methods however, of weed control such as use of herbicides and/or manual weeding had considerable differential effect on the control of weeds and consequently on yield of the crop. The combination of butachlor at 2.0 kg/ha and one hand weeding proved better than butachlor application only, while two hand weedings proved to be the best.

INTRODUCTION

The problem of weeds is severe in upland rice. Weeds germinate simultaneously with the crop seedlings and grow luxuriantly thereby causing severe competition with the crop. Losses in rice yield due to weeds might range from as low as 5% to as high as total failure of the crop, depending on the type and intensity of weed infestation (Pande and Bhan, 1966). The extent of yield reduction due to weeds in upland rice is estimated to vary from 43 to 84 per cent (Pillai and Rao, 1974; Rao *et al.,* 1977).

Hand weeding, though the most effective method of weed control in upland rice, fails to return the expected benefit because of lack of timely operation. In addition to the labor unavailability at the times when they are needed most, the labor requirement (300-1200 man hours/hectare) is also quite high. Further, in view of the varying weed flora, their time of emergence and active growth phases, the time and method of their effective control are likely to be different. An investigation was therefore taken up to find out the effective combination of tillage practice, manual weeding and use of herbicide for controlling weeds in upland rice.

MATERIALS AND METHODS

The experiment was conducted during the wet season (June-July to October-November) of 1978 and 1979, at the experimental farm of the Department of Agricultural Engineering, Indian Institute of Technology, Kharagpur (West Bengal). The type of soil was lateritic sandy clay loam with pH of 5.30 and 0.35% organic matter, 0.0007% available phosphorus and 0.0125% exchangeable potassium. In 1978, two tillage treatments — one plowing and two harrowings, and one plowing and three harrowings, and four other methods of weed control — application of butachlor at 2 and 3 kg/ha, two hand weedings, and application of butachlor at 2 kg/ha, and one hand weeding constituted eight treatment combinations (Table 1). Based on the results of 1978, the tillage and other weed control treatments were modified in 1979 to assess their effect on weed growth and crop yield in a more precise way. The tillage treatments included plowing once 21 days before sowing and harrowing twice 15 days after plowing, plowing followed by harrowing 21 days before sowing and second harrowing 15 days after the first operation, and plowing followed by two harrowings, 6 days before sowing (Table 1.1). Other methods of weed control were the application of butachlor at 2 kg/ha, two hand weedings, and application of butachlor at 2 kg/ha. and one hand weeding. The treatments were replicated thrice and the experiment was laid out in split-plot design. Ratna, a rice variety of medium duration (115-120 days) was grown as the test crop. It was dry seeded in solid rows at 20 cm at a seeding rate of 100 kg/ha. The observations recorded on crop growth included percent germination, yield and yield attributes. Weed competition under different methods of weed control was studied through the dry matter production of weeds.

RESULTS AND DISCUSSION

The differences in the degree of weed control as reflected by the dry matter accumulation of weeds (Figure 1.0) due to various tillage treatments during both years were of low magnitude. Succeeding harrowings after the initial plowing might have helped kill the first flush of weeds and might have also brought more weed seeds to the soil surface, which subsequently germinated and competed with the crop. The grain and straw yields as well as other yield attributes (Table 1.0 and 1.1) also remained unaffected suggesting that no advantage could be gained due to different tillage treatments.

Among the other methods of weed control, higher grain yield was from two hand weedings in comparison with application of butachlor at 2 or 3 kg/ha and combination of butachlor at 2 kg/ha and one hand weeding. (Tables 1.0 and 1.1). All the yield contributing characters were higher with hand weeding.

Application of butachlor resulted in significant reduction of crop germination (Table 1.0 and 1.1). There was rainfall soon after the application of butachlor during both years, which might have leached the herbicide to lower depth in the seeding zone, thereby resulting in toxicity to germinating

Table 1.1 Germination yield and yield attributes of upland rice as influenced by method of weed control (1976)

Treatment	Germination (%)	Panicles/ m^2	Spikelets/ panicle	Filled Spikelets (%)	1000 grain weight/g	Grain yield q/ha	Straw yield q/ha
A. *Main plot:* Tillage							
Ploughing 21 days before sowing and harrowing twice 15 days after Ploughin	61.1	261.0	62.8	32.3	20.1	6.1	22.3
Ploughing followed by one harrowing 21 days before sowing and second harrowing 15 days after the first operation	63.3	277.3	64.1	31.6	19.9	7.4	23.6
Ploughing followed by two harrowing 6 days before sowing	62.2	252.0	62.9	30.8	19.9	6.1	23.3
S.Em ±	NS	NS	NS	NS	NS	NS	NS
C.D. at 5%							
C.D. at 1%							
B. *Sub plot:* Manual weeding and/or weedicide application							
Two hand weedings	81.3	328.2	66.2	32.8	20.6	9.5	32.5
Butachlor 2 kg/λ a	53.6	201.4	58.0	30.5	19.1	3.8	14.9
Butachlor 2 kg/λ a and one hand weeding	51.8	260.7	65.6	31.4	20.3	6.3	21.8
S.Em ±	2.0	9.6	1.8	NS	0.5	0.5	0.9
C.D. at 5%	4.3	20.6	4.0		1.1	1.1	2.0
C.D. at 1%	6.0	28.9	5.6		—	1.6	2.8

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Table 1.0 Germination yield and yield attributes of upland rice as influenced by method of weed control (1978)

Treatment	Germination %	Panicles/ m^2	Spikelets/ panicle	Filled Spikelets %	1000 grain weight g	Grain yield q/ha	Straw yield q/ha
A. *Main plot:* Tillage							
One ploughing and two harrowings	55.1	257.3	65.0	66.3	20.4	13.5	22.8
One plough and three harrowings	53.3	252.9	62.5	65.5	19.6	12.4	21.4
S. Em ±	NS	NS	NS	NS	NS	NS	NS
C.D. at 5%							
C.D. at 1%							
B. *Sub plot:* Manual weeding and/or weedicide application							
Two hand weedings	76.1	337.5	70.0	69.7	21.0	21.6	33.3
Butachlor 2 kg/λ a	47.2	210.8	59.0	63.8	19.5	9.0	16.3
Butachlor 3 kg/λ a	45.6	206.4	57.3	62.5	19.4	8.2	15.3
Butachlor 2 kg/λ a weeding	48.0	265.3	68.7	67.6	20.1	13.1	23.6
S.Em γ	2.3	12.2	2.2	2.0	0.5	1.1	1.2
C.D. at 5%	4.9	26.6	4.7	4.4	1.0	2.4	2.6
C.D. at 1%	6.9	37.2	6.6	—	1.4	3.4	3.6

crop seeds. Occurrence of heavy rainfall immediately after preemergence application of herbicides like dinitramine, butachlor, piperophos-dimethamethryn, thiobencarb and nitrofen was reported to affect the germination considerably (Rao *et al.,* 1977). Further, since the herbicide had moved below the soil surface, the weed seeds present on the soil surface escaped toxicity of the chemical. Hence they could germinate and grow luxuriantly.

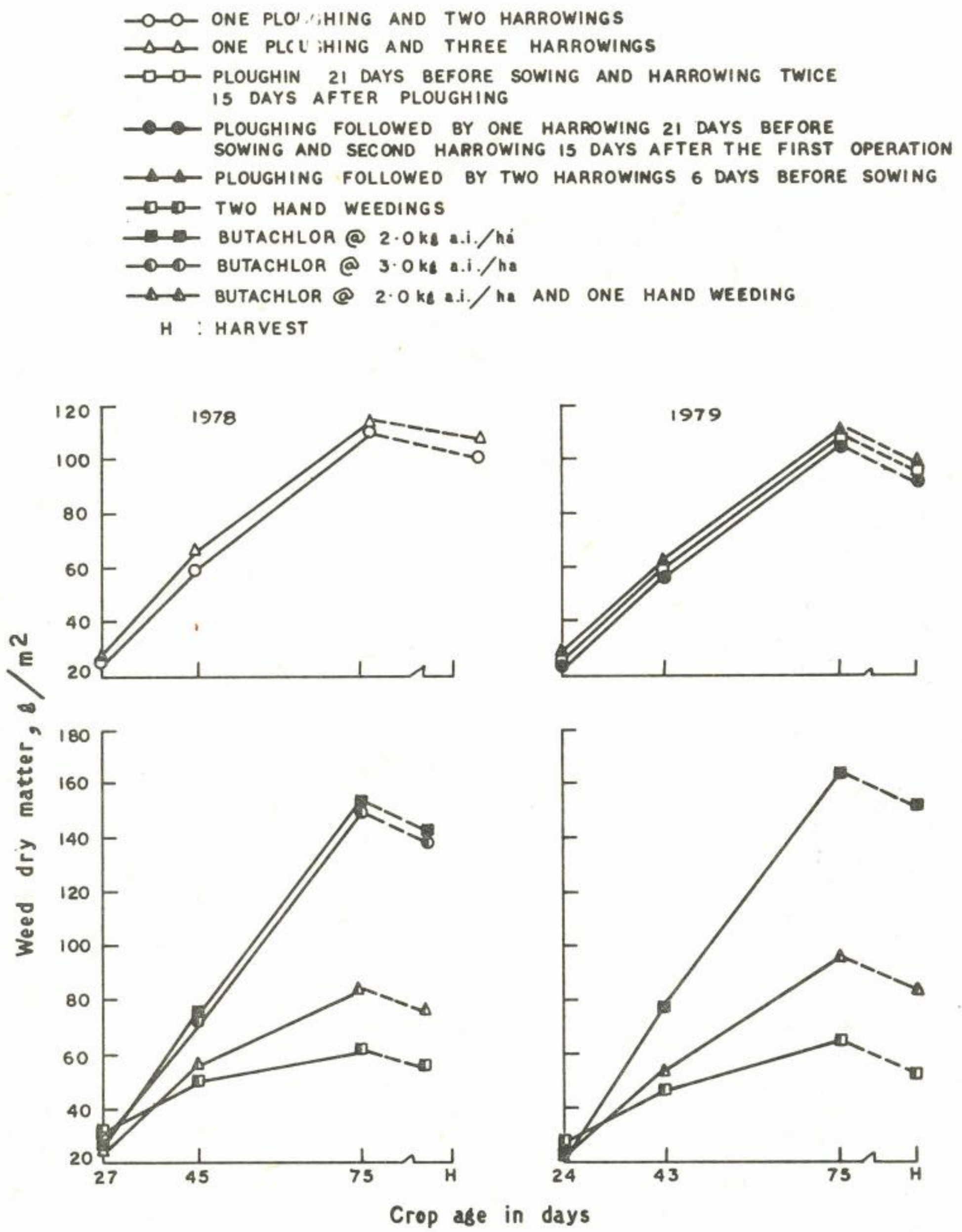

FIG.1·0 DRY MATTER PRODUCTION OF WEEDS AS INFLUENCED BY METHOD OF WEED CONTROL

Butachlor seems to be unsuitable for weed control in upland rice. This is due to the fact that the rainfall may coincide with the time of herbicide application, causing uncontrolled movement of water in the soil and leaching of the chemical to the seed zone, killing the germinating crop seeds.

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IMPROVEMENT IN HERBICIDE APPLICATION TECHNIQUE AND APPLICATION TIMING IN TRANSPLANTED AND BROADCAST-SEEDED FLOODED RICE

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ABSTRACT

Experiments during the 1982 and 1983 dry seasons at the International Rice Research Institute (IRRI) evaluated the relative efficiency of applying oxadiazon [2-*tert*-butyl-4 (2, 4-dichloro-5-isopropoxyphenyl)-1, 3, 4-oxadiazon in 5-one], thiobencarb [S-(4-chlorobenzyl) NN diethylthiocarbamate], butachlor [N-(butoxymethyl)-2-chloro-2', 6'-diethylacetanilide], and pendimethalin [N-(1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine] without dilution for weed control in irrigated rice (*Oryza sativa* L.). Experiments involving time of application of liquid herbicides without dilution and granular herbicides in broadcast-seeded flooded rice were also conducted.

Herbicides applied with sprinkler bottle controlled weeds as effectively as herbicides applied with a knapsack sprayer both before and after plantings. Treated plots gave yields significantly higher than those of the untreated check and comparable with those of the hand-weeded plots. Sprinkler bottle application also gave the same results in broadcast-seeded flooded rice applied 6 days after seeding (DAS).

Application of granular herbicides such as butachlor and piperophos (S-2-methyl-piperidinocarbonyl methyl 0 0-dipropyl phosphorodithioate)-2, 4-D (2, 4-dichlorophenoxy acetic acid) at 6 and 3 days before seeding (DBS) provided better control of the annual weeds and improved grain yields than did their application at 6 DAS.

The results suggest that undiluted application using the sprinkler bottle is a viable alternative approach in reducing herbicide application cost in transplanted and broadcast-seeded flooded rice without sacrificing weed control and rice yields.

Results also suggest that in broadcast-seeded flooded rice some herbicides can be applied before seeding without severe toxicity to the corp. Because they are applied strictly before weed emergence, weed control is further improved and grain yields are higher.

INTRODUCTION

The usual method of chemical application is using a large volume of water. Most scientists, however, consider this method inefficient. In the tropics, about the only sprayers available to the farmers are those that deliver the spray at several hundred liters per hectare, which is a burden to the farmers.

In general, the basic design of spraying equipment has changed little since the turn of the century (Lodeman, 1896). The changes have been primarily in the size and cost of the equipment. Our challenge is to design applicators suitable for small farmers who have limited cash and education. Most of the researches done, however, were on chemical and evaluation aspects, and meager researches were carried out to application methods (Matthews, 1979). Only recently has research on application technology intensified because of increased pressures on costs of chemicals and their applications. Current developments in application techniques are encouraging. For example, in Thailand, especially formulated oxadiazon applied directly undiluted from its container bottle through its modified nippled cap effectively controlled weeds in irrigated lowland rice (Gosney, 1980). A recent report at IRRI showed that herbicides such as oxadiazon, butachlor, thiobencarb, and pendimethalin applied undiluted on plots with 3-5 cm standing water using a sprinkler bottle (a plastic bottle with calibrated perforated cap) controlled weeds as effectively as diluted spray treatment of butachlor applied by knapsack sprayer (IRRI, 1982).

Research should not be focused on application method alone; application timing, which is important in broadcast-seeded flooded rice, should also be considered. At this time, direct-seeding is expected to increase as labor cost increases (Arceo and Mercado, 1981; De Datta, 1981). Although it eliminates seedbedding and transplanting, weed control on the other hand, is more difficult. The only option is to use chemicals for weed control because hand weeding and cultivation are difficult. However, chemical weed control becomes more exacting in direct-seeded rice than in transplanted rice because of the similarity in growth stages between rice and weed seedlings (De Datta and Bernasor, 1973). Also, if too much water is present in the field, herbicides may be toxic to rice plants (Moody, 1982). A practical method of improving crop safety from herbicides in broadcast-seeded flooded rice is adjusting the application time. For example, in irrigated rice, Arceo and Mercado (1981) reported that butachlor at 1.0 kg/ha gave better control of the grasses and gave higher yields when applied 2 DBS than when applied 6 DAS. The use of naphthalic anhydride (NA) to protect pregerminated rice from herbicide injury was tried at IRRI. Mabbayad and Moody (1982) reported that grain yields was not affected by time of application when seeds were treated with NA. Without NA, however, grain yields were highest when butachlor was applied 3 DBS than when applied 3 DAS.

On the the basis of these observations, we ran a series of weed control experiments in irrigated rice with the following objectives:

1. to evaluate further the relative efficiency between undiluted and high-dilution herbicide applications on weed control in transplanted and broadcast-seeded flooded rice, and

2. to evaluate the efficiency of herbicides applied before and after seeding in broadcast-seeded flooded rice.

MATERIALS AND METHODS

Experiments involving the undiluted herbicide application technique and, subsequently, herbicide application timing were conducted at IFRI. The soil at IRRI farm is Maahas clay (pH 6.8; organic matter, 2%; CEC, 45 meq/100 g Aquic Tropudalf). Herbicides applied undiluted and those applied with the conventional knapsack sprayer using 350 l/ha dilution were compared for efficiency. In general, all the herbicides used needed dilution before application. Time of application in broadcast-seeded flooded rice was studied separately. All experiments were conducted under good irrigation with continuous submergence in 5 cm water.

Undiluted herbicide application

During the 1982 dry season, a sprinkler bottle was used in separate trials for transplanted and broadcast-seeded flooded rice.

Undiluted herbicides were sprinkled directly into plots with 3.5 cm standing water using a plastic bottle with calibrated perforated cap. The computed amount of the herbicides was applied per plot to approximate the exact rate of application per unit area.

In transplanted rice, oxadiazon at 0.6 kg/ha, butachlor at 1.0 kg/ha, thiobencarb at 2.0 kg/ha, and pendimethalin at 0.75 kg/ha were used and each herbicide was applied undiluted using a sprinkler bottle, or diluted using a knapsack sprayer. Both application methods were evaluated at 2 application times — preplanting treatment or 1 day before transplanting and postplanting treatment or 2 days after transplanting (DT). In broadcast-seeded flooded rice, the same herbicides were applied 6 DAS each at 2 rates. Each herbicides performed similarly at low and high rates; thus only the results at low rates are presented in this paper (Fig. 2). Granular butachlor and untreated checks were included for comparison.

Time of herbicide application

During the 1983 dry season, two experiments were conducted involving time of herbicide application in broadcast-seeded flooded rice. In one experiment, liquid oxadiazon (sprinkler bottle formulation) and butachlor at 0.4 and 1.0 kg/ha, respectively, were applied using a sprinkler bottle at 6 and 3 DBS and 6 DAS. In the other experiment, granular butachlor at 0.75 and 1.0 and piperophos-2, 4-D at 0.3 and 0.5 kg/ha were broadcast applied using the same application time. In both trials, untreated checks were maintained for comparison.

The treatments were laid out in 3 x 5 m plots following a randomized complete block design with 3 to 4 replications. Rice was transplanted at 20 cm x 20 cm spacing with 3 to 4 plants/hill. In direct-seeded rice, pregerminated seeds were broadcast on a well-puddled soil at approximately 80 to 100 kg dry seeds/ha. The variety used in all experiments were IR36 with about 110-day duration.

In all trials, weeds were sampled (sampling time is indicated in respective figure/table) and classified into broadleaf weeds, grasses, and sedges. Weeds were oven-dried and the weight of each weed group was recorded. Toxicity was rated visually at 2 weeks after herbicide application in broadcast-seeded flooded rice only. Grain yields from all trials were recorded and subjected to statistical analysis. All other cultural practices were at optimum levels.

RESULTS AND DISCUSSION

Undiluted herbicide application

Transplanted rice. The grasses — *Echinochloa crus-galli* ssp. *hispidula* (Retz.) Honda and *E. glabrescens* Munro ex Hook. f. — made up 90% of the total weeds sampled. Other weeds of minor importance were the broadleaf weed *Monochoria vaginalis* (Burm. f.) Presl and the sedge *Cyperus difformis* L.

Regardless of application time and method, all herbicide treatments gave adequate weed control generally similar to the hand-wheeded check (Fig. 1). When the application methods were compared at each time of application, dry weed weights sampled from the diluted and undiluted treatments of each of the herbicides used were similar. Likewise, with each herbicide and under each method of application, generally more weeds were present in preplanting than in postplanting treatments. However, dry weed weights for both application timings were similar.

Irrespective of application method and timing, all herbicide treatments gave grain yields significantly higher than those of the untreated check and generally comparable with those of the hand-weeded check.

Moreover, the oxadiazon- and thiobencarb-treated plots gave similar grain yields regardless of application method or timing used (Table 1). Preplanting treatment with undiluted butachlor gave higher yields than with diluted butachlor. When butachlor was applied as a postplanting treatment, the difference in grain yields between application methods was not significant. Postplanting treatment with diluted butachlor gave higher yields. Regardless of application time yields of treatments with undiluted butachlor were similar.

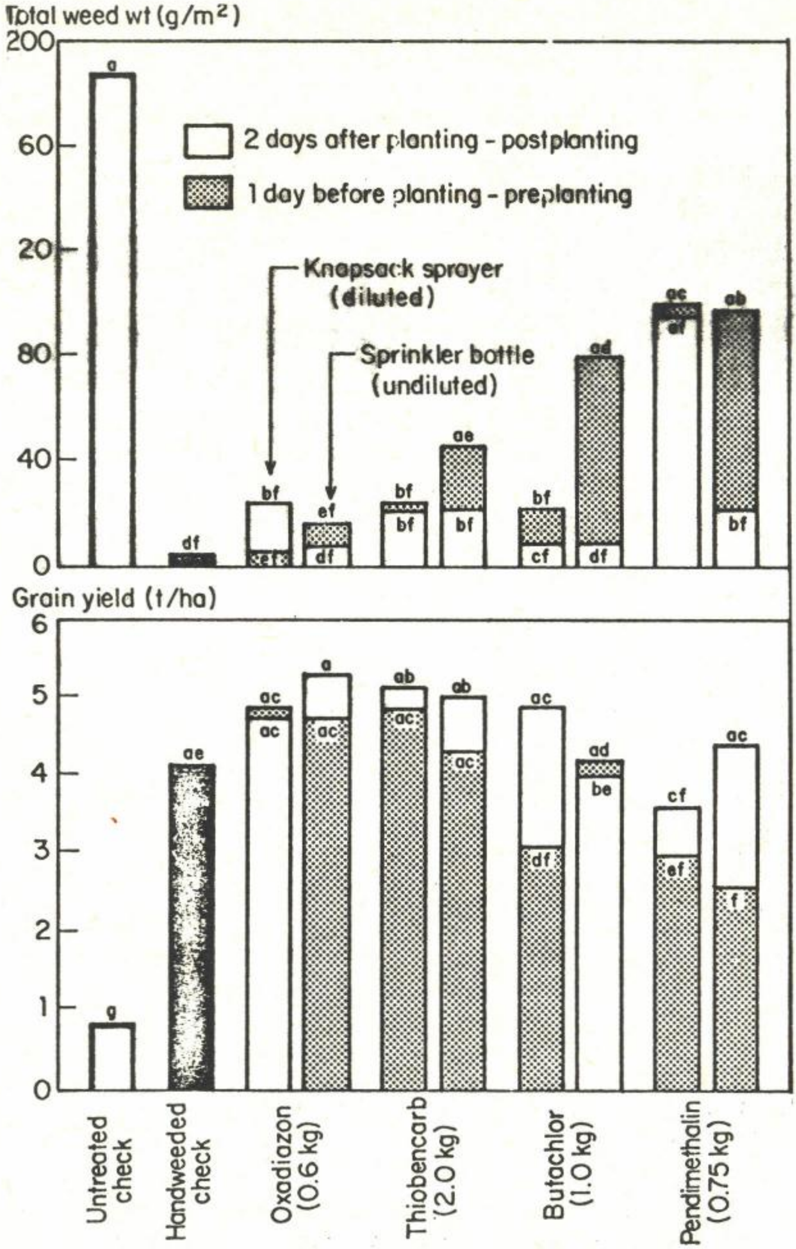

Fig. 1. Total weed weight at harvest and grain yield of transplanted IR36 rice as affected by method and time of herbicide application (average of 3 replications. Bars having a common letter are not significantly different by DMRT at the 5% level). IRRI, 1982 dry season.

Table 1. Effects of method and time of application of 4 liquid herbicides on yields of irrigated transplanted IR36. IRRI, 1982 dry season. Average of 3 replications.

Application method	Herbicide[a]											
	Oxadiazon			Thiobencarb			Butachlor			Pendimethalin		
	Pre-planting	Post-planting	Difference	Pre-planting	Post-planting	Difference	Pre-planting	Post-planting	Difference	Pre-planting	Post-planting	Difference
Knapsack sprayer (Diluted)	4.9	4.8	0.1^{ns}	4.9	5.2	-0.3^{ns}	3.1	4.9	-1.8^{**}	3.0	3.6	0.6^{ns}
Sprinkler bottle	4.8	5.3	-0.5^{ns}	4.4	5.1	-0.7^{ns}	4.3	4.0	0.3^{ns}	2.6	4.4	-1.8^{**}
Difference	0.1^{ns}	-0.5^{ns}		0.5^{ns}	0.1^{ns}		-1.2^{*}	0.9^{ns}		0.4^{ns}	-0.8^{ns}	

[a]Preplanting = applied 1 DBT, postplanting = applied 2 DAT.
**Significant at 5% level, **Significant at 1% level, ns = Not significant.*

With pendimethalin, yields did not significantly differ between application methods. Yields, however, were generally lower when pendimethalin was applied before planting.

Broadcast-seeded flooded rice. Grasses made up 97% of the total weed weight. Other weeds were of minor importance.

Regardless of application method, oxadiazon, butachlor, and pendimethalin treatments provided adequate weed control and gave similar dry weed weights — the resulting yields were significantly higher than those of the untreated check (Fig. 2). Thiobencarb gave significanlty less dry weed weight when applied with dilution than when applied without dilution.

However, whether diluted or undiluted, thiobencarb produced higher yields than did the butachlor check, undiluted butachlor, and diluted pendimethalin. All other herbicides, regardless of application method, performed similarly to the butachlor check.

All herbicides when applied 6 DAS were slightly to severely toxci to broadcast-seeded flooded rice (Table 2). However, only pendimethalin significantly reduced tiller production of rice, regardless of the application method.

When averaged over 4 herbicides, differences in dry weed weights for each weed class and yield were not significant regardless of the application method used (Table 3).

Results of both trials suggest that application of undiluted herbicide with a sprinkler bottle is an effective alternative to application by knapsack sprayer in transplanted and broadcast-seeded flooded rice without sacrificing weed control and rice grain yields.

Time of herbicide application

Two experiments in broadcast-seeded flooded rice were conducted. Undiluted herbicides were applied with a sprinkler bottle in one experiment and granular herbicides in the other.

Experiment 1. At later crop growth, the perennial *Scirpus maritimus* L. became dominant comprising 81% of the total weed weight at harvest.

The presence of standing water in some plots during seeding aggravated initial herbicide toxicity and resulted in apparent reduction in crop stand 30 DAS in the 6- and 3-DBS treatments compared with the 6-DAS treatments of both oxadiazon and butachlor (Table 4). This reduction in crop stand was significant in 6- and 3-DBS butachlor treatments and 6-DBS oxadiazon treatments. In general, only the 6-DBS treatment of butachlor had a significantly lower crop stand than the untreated check. The panicle number at harvest, however, did not significantly differ regardless of herbi-

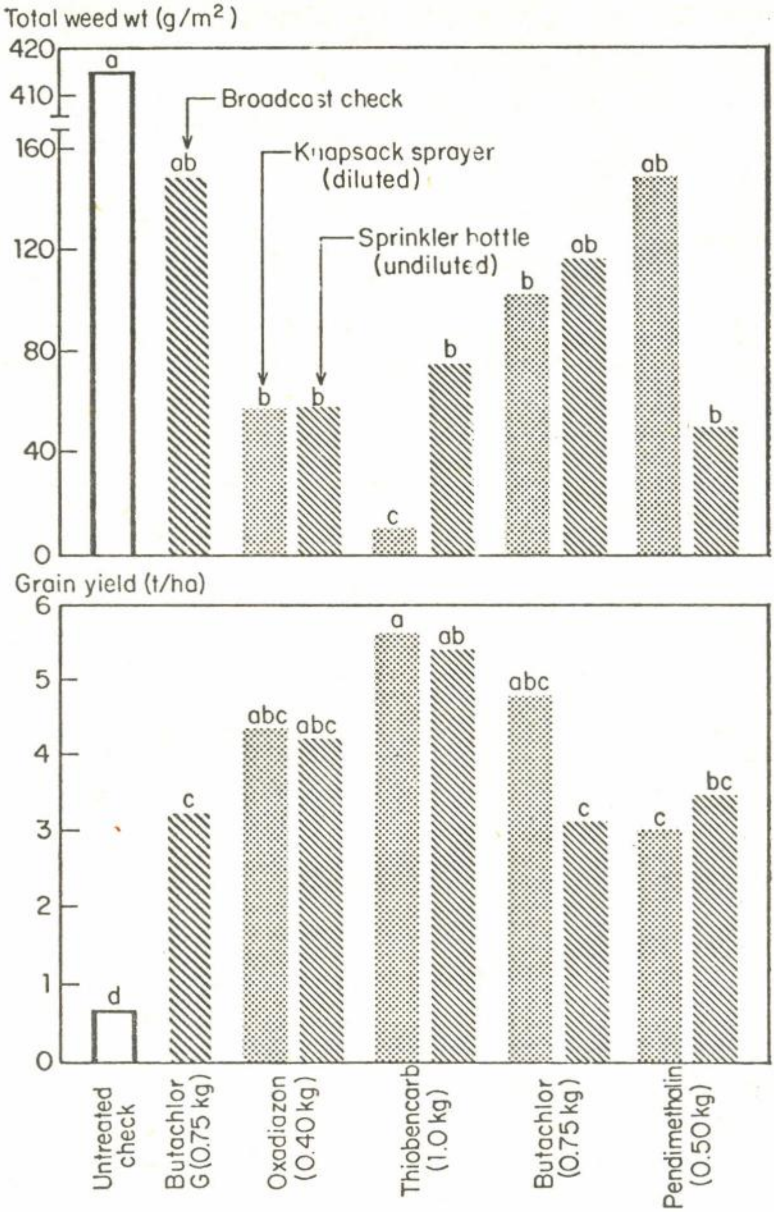

Fig. 2. Total weed weight at harvest and grain yield of broadcast-seeded flooded IR36 as affected by method of herbicide application (average of 3 replications. Bars with a common letter are not significantly different by DMRT at the 5% level). IRRI, 1982 wet season.

Table 2. Effect of herbicide application method on crop tolerance and tiller count of broadcast seeded flooded IR36 rice — herbicide applied 6 days after seeding (DS). IRRI, 1982 dry season. Average of 3 replications. Separation of means in a column by DMRT at the 5% level.

Treatment	Application Rate (kg / ha)	Method[1]	Visual toxicity rating[2]	Tiller count at 30 DAS (no./m^2)
Oxadiazon	0.4	Knapsack sprayer	4	352 a
Oxadiazon	0.4	Sprinkler bottle	2	384 a
Thiobencarb	1.0	Knapsack sprayer	1	400 a
Thiobencarb	1.0	Sprinkler bottle	2	352 a
Butachlor	0.75	Knapsack sprayer	1	352 a
Butachlor	0.75	Sprinkler bottle	4	432 a
Pendimethalin	0.5	Knapsack sprayer	7	208 b
Pendimethalin	0.5	Sprinkler bottle	6	205 b
Butachlor (granular)	0.75	Broadcast check	1	412 a
Untreated check	—	—	0	400 a

[1] Knapsack sprayer = dilluted spray, Sprinkle bottle = applied without dillution.
[2] Rated 2 weeks after herbicide application (Scale used: 0-10; 0 — no toxicity, 10 — complte kill).

cide and application time, suggesting the ability of IR36, a high-tillering variety, to produce new tillers. In one report, Moody (1982) has indicated that a 30% stand reduction had little or no effect on the final grain yield. The farmers, however, unaware of this fact, would easily react to any crop injury from herbicide toxicity.

In our trial, the grain yields were generally low because of infestation by *S. maritimus* which is tolerant of the herbicides used. Among the treatments, only the application of oxadiazon at 6 DAS gave significantly higher yield than the untreated check. Nevertheless, the results suggest that the margin of herbicide toxicity in broadcast-seeded rice is very narrow and much dependent on the water status in the field.

Table 3. Effect of herbicide application methods on weed control and grain yield of broadcast-seeded flooded rice — herbicide applied 6 days after seeding (average of 3 replications and 4 herbicides). IRRI, 1982 wet season.

Application method	Weed weight (g/m^2)			Grain yield (t/ha)
	Broadleaf weeds	Grasses	Sedges	
Kanpsack sprayer (diluted)	1	42	38	4.5
Sprinkler bottle (undiluted)	3	44	34	4.1
Difference	-2^{ns}	-2^{ns}	4^{ns}	0.4^{ns}

ns = Not significant at 5% level.

Experiment 2. The grasses *E. crus-galli* ssp. *hispidula* and *E. glabrescens* and the perennial sedge *S. maritimus* comprised 63% and 29% of the weed population, respectively. Other weeds were minor.

In general, application of granular butachlor and piperophos-2, 4-D each at 2 rates more adequately reduced the dry matter of the grasses than did the application at 6 DAS (Fig. 3), In situations where there was good control of the grasses, *S. maritimus* increased in dominance, as indicated in its higher dry weights sampled from most 6- and 3-DBS treatments of the herbicides.

In terms of yields, application at 3 DBS gave higher yields than application at either 6 DBS or 6 DAS and the untreated check (Fig. 4). These differences were significant at both rates of butachlor and at the lower rate of piperophos-2, 4-D. Yields from 6-DBS treatment were lower possibly because of the presence of *S. maritimus*, which had a 3-day headstart over the 3 DBS treatment. The yield response would have been different under a

Table 4. Effect of herbicide application time on weed control crop tolerance, stand count, panicle number and grain yield of broadcast-seeded flooded IR36 rice. IRRI, 1983 dry season. Average of 3 replications. Separation of means in a column by DMRT at the 5% level.

Herbicide treatment	Application time	Total weed wt. (g/m^2)	Visual toxicity rating[1]	Stand count at 30 DAS (no/m^2)	Panicle no. at harvest (no/m^2)	Grain yield (t/ha)
Oxadiazon (0.4)	6 DBS	236 a	5	128 bc	244 a	1.3 bc
Oxadiazon	3 DBS	144 ab	5	192 ab	424 a	2.8 ab
Oxadiazon	6 DAS	52 b	3	276 a	372 a	3.8 a
Butachlor (1.0)	6 DBS	126 ab	4	100 c	276 a	0.7 c
Butachlor	3 DBS	192 ab	3	128 bc	316 a	1.0 c
Butachlor	6 DAS	194 ab	3	288 a	428 a	2.1 bc
Untreated check	—	53 ab	0	212 ab	404 a	2.2 bc

[1] *Rated 2 weeks after herbicide application (scale used: 0-10; 0 — no toxicity, 10 — complte kill).*

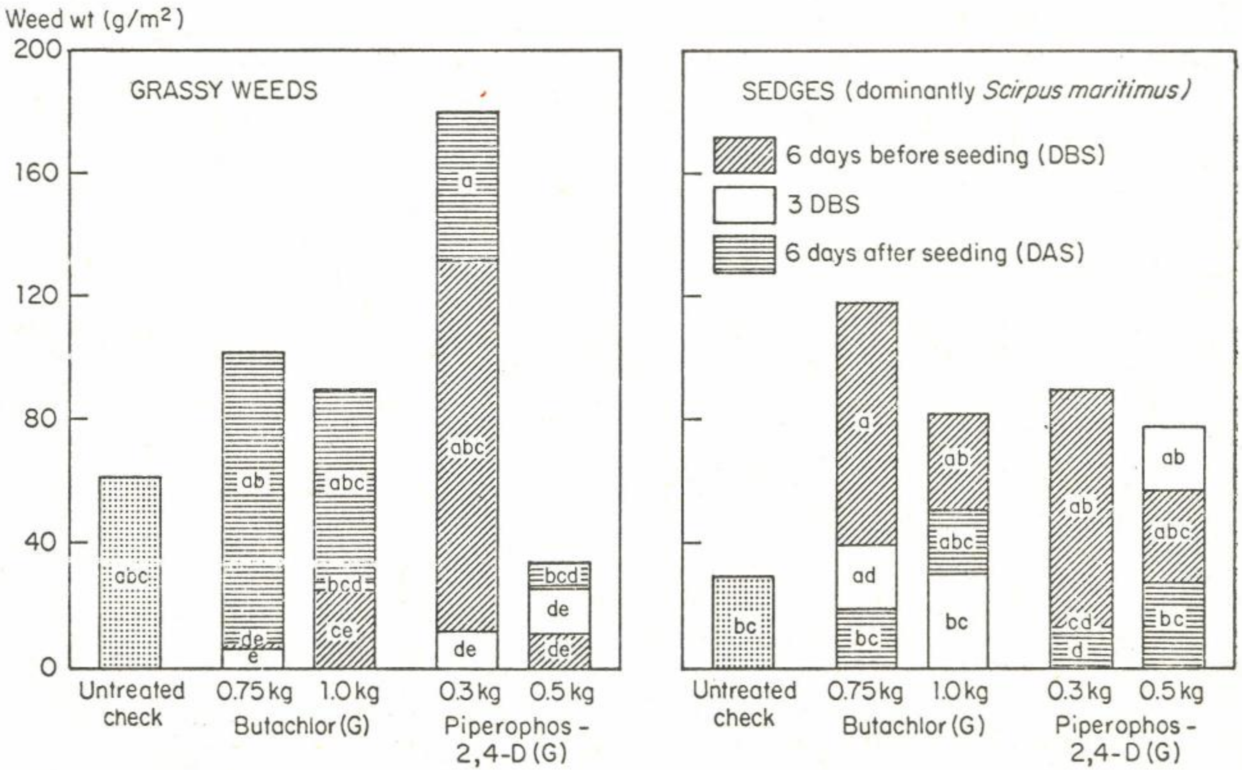

Fig. 3. Weed weight (taken at flowering stage of grasses) in broadcast-seeded flooded IR36 rice as affected by time of herbicide application (average of 4 replications. Bars with a common letter under each group are not significantly different by DMRT at 5% level). IRRI, 1983 dry season.

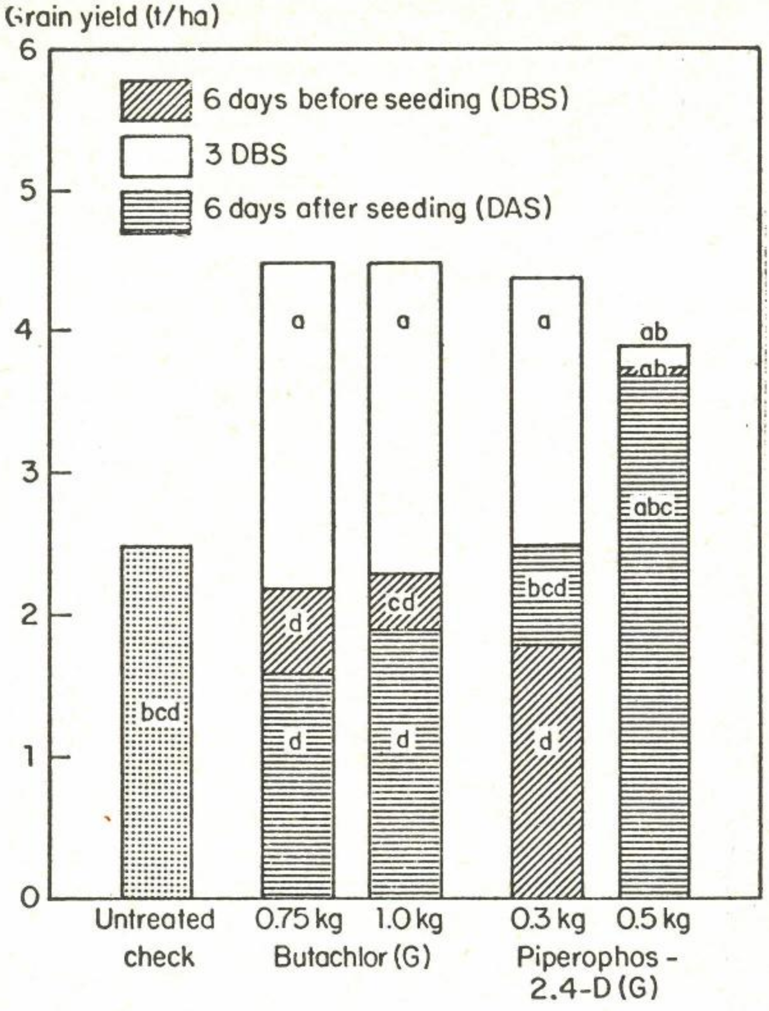

Fig. 4. Grain yield of broadcast-seeded flooded IR36 as affected by time of herbicide application (average of 4 replications. Bars having a common letter are not significantly different by DMRT at the 5% level). IRRI, 1983 dry season.

purely grassy weed situation. On the other hand, application at 6 DAS of both herbicides gave relatively poor grass control, which resulted in lower grain yields, particularly with the butachlor treatment (Table 5). In general, both herbicides were initially slightly toxic to rice but the crop recovered and at 30 DAS completely grew out of the injury, regardless of application time.

Table 5. Effect of time of herbicide application on weed control, stand count and grain yield of broadcast-seeded flooded rice. IRRI, 1982 wet season. Average of 4 replications and 2 herbicide rates. Separation of means in a column by DMRT at the 5% level.

Application time	Weed weight (g/m^2) Grasses	Weed weight (g/m^2) *Scirpus maritimus*	Stand count[d] (no/m^2)	Grain yield (t/ha)
		BUTACHLOR (G)		
6 DBS	16 b	100 a	196a	2.2 b
3 DBS	17 c	36 b	168 a	4.5 a
6 DAS	94 a	36 b	152 a	1.7 b
		PIPEROPHOS + 2, 4-D IPE (G)		
6 DBS	72 b	71 a	176 a	2.8 b
3 DBS	20 c	44 ab	184 a	4.1 a
6 DAS	107 a	20 b	172 a	3.1 a

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ANOTHER CRITERION IN DEFINING THE WORLD'S WORST WEEDS

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ABSTRACT

Weeds host many species of arthropods, nematodes, pathogens, and vertebrates which affect crops adversely. The impact of a weed on a crop may include the direct effect of competition (interference), the indirect effect of serving as a reservoir for pests attacking the crops, and the debilitating effect of the pest on crop vigor and competitive ability. A re-ranking of the world's worst weeds on the basis of the numbers of species of arthropods and nematodes hosted places *Chenopodium album* L. in top position, followed by *Cyperus rotundus* L, *Cynodon dactylon* (L.) Pers., *Echinochloa colona* (L.) Link, *Sorghum halepense* (L.) Pers., and *Amaranthus spinosus* L., each hosting more than 15 species of pests affecting crops. The significance of the weed hosts as reservoirs concept in crop production will become increasingly apparent as more specific information is brought together. The weed hosts as reservoirs concept is a practical application of integrated crop protection.

INTRODUCTION

Holm *et al.* (1977) identified the world's worst weeds on the basis of the frequency with which they were reported in a world-wide survey of weeds infesting the major crops of the world. Five categories were used in rating plant weediness. The plant was: 1) a serious weed, 2) a principal weed 3) a common weed, 4) present in the flora. These terms were not defined precisely, but the logical argument was presented that weed researchers and farmers understood from experiences and could distinguish whether a plant was a serious, principal, or common weed. Some of the factors implicit in these decisions were the level of competition of the weed in the cultivated fields and grassland, which affect the productivity and yield. The toxic effect of a weed on man and animals was also a factor in describing weediness. Another aspect was the effect of the weed in decreasing the quality of the crop or animal product.

Holzner and Numata (1982) say that non-group agrestal plants are weeds and unwanted because they interfere with the crop by competition for light, water, and mineral nutrients and by allelopathic effects. They reason that it is difficult to separate the competitive and allelopathic effects of one plant on another, consequently they use the term interference to include both aspects. The colonizing or pioneering ability of a plant, they point out, does not make a weed of the plant; but its competitive relationships do. Weeds impede crop harvest and are, therefore, unwanted. They have a negative effect on the quality of the agricultural product by being poisonous or by causing discolorations, off-flavors, or orders. Weeds also host diseases and parasites of plants and are, consequently, unwanted.

Implicit in discussion of weeds and their degree of weediness is the difficulty of their control. Difficulty of control may relate to the means of control, the means of reproduction, or the development of resistant strains. The perspective of ease of control is quite different among biological, chemical, and physical-mechanical means. Whether weeds are annual or perennial — "seed-weeds" or "root-weeds" — whether they reproduce from rhizomes, roots, or seeds interfaces with the system of farming in determining the difficulty of control. Whenever chemical weed control is used the development of resistant strains of weeds is a possibility

To summarize, the factors defining a weed and weediness include:

1. Competitive ability,
2. Effect on crop quality,
3. Effect on harvesting,
4. Means of reproduction,
5. Means of control,
6. Development of resistant strains, and
7. Hosting of other organisms.

Weeds as Hosts

Let us evaluate the world's worst weeds identified by Holm, et al on the basis of the numbers of species of arthropods and nematodes affecting crops which those weeds have been reported to host. These data were extracted from published reports of weeds as reservoirs (Bendizen et al., 1979; 1981; 1982) and weed hosts (Bendixen 1981; 1982; Manuel et al., 1980; 1981; 1982; Yassin, 1982) of organisms affecting crops.

Chenopodium album hosted more species of arthropods affecting crops than any other species (Table 1). It hosted 19, followed by *Echinochloa colona* (L.) Link with 14, and *Cynodon dactylon* with 11 species.

Cyperus rotundus L. led the list in the number of species of nematodes affecting crops that were hosted. It hosted 19, while C. album hosted 15, *C dactylon* hosted 12, and *Sorghum halepense* hosted 10 species.

Table 1. Number of species of arthropods and nematodes affecting crops reported to be hosted by the 17 worst weeds of the world.

Host	Longevity	Species hosted Arthropods	Nematodes	Total
		No.		
Cyperus rotundus L.	P[1]	7	19	26
Cynodon dactylon (L.) Pers.	P	11	12	23
Echinochloa glabrescens Munro ex Hook	A	8	5	13
Echinochloa colona (L.) Link	A	14	3	17
Eleusine indica (L.) Gaertn.	A	5	7	12
Sorghum halepense (L.) Pers.	P	7	10	17
Imperata cylindrica (L.) P. Beauv.	P	5	0	5
Portulaca oleracea L.	A	3	6	9
Chenopodium album L.	A	19	15	34
Digitaria sanguinalis (L.) Scop.	A	2	11	13
Convolvulus arvensis L.	P	7	5	12
Avena fatua L.	A	6	7	13
Amaranthus spinosus L.	A	9	8	17
Cyperus esculentus L.	P	4	6	10
Paspalum conjugatum Berg.	P	0	1	1
Rottboellia a exaltata L. f.	A	0	0	0
Amaranthus hybridus L.	A	6	3	9
Subtotal	P	25	27	52
Subtotal	A	54	27	81

1/ P = perennial; A = annual

If the world's worst weeds are ranked according to the total number of arthropods plus nematodes they are reported to host, *C. album* leads the list, by a fair margin, with 34 species; second is *C. rotundus* with 26; *C, dactylon* is third with 23; and *E. colona*, *S. halepense*, and *A. spinosus* tie for fourth place with 17 species being hosted.

The seven perennial weed species hosted 25 different species of arthropod and 27 different species of nenatodes, for a total of 52; while the 10 annual species hosted 54 and 27, respectively, for a total of 81 species. The average number of species hosted per perennial weed species is 3.6 arthropod and 3.9 nematode species; for annual weed species the numbers are 5.4 and 2.7, respectively. These data show that the annual weed species tend to host more arthropods affecting crops than do the perennial species, while for nematodes the opposite is true.

The low numbers of arthropods or nematodes reported to be hosted by some of the weed species may reflect the amount of research devoted to the matter as well as the suitability of the weed species as a host.

The impact on crop yield of weed hosts as reservoirs for organisms affecting crops may be worthy of further consideration. Through the processes of natural selection, weed hosts have developed a certain degree of tolerance for the organisms they host. They may, therefore, be more tolerant of those pests than the crops with which they compete and, thus, be in a competitively advantageous position. When pest resistant or tolerant cultivars of crops are used, competition from the weeds hosting those pests would expectantly be less.

To consider an example, *S. halepense* serves as the over-wintering host in Ohio of two maize virus diseases — maize dwarf mosaic and maize chlorotic dwarf virus. In the valleys where fields are infested with *S. halepense*, virus tolerant cultivars are less susceptible to disease and are more competitive with the weed than the virus susceptible cultivars.

Where pest resistance or tolerance in crop species is not available or is not sufficient, crop yields will be reduced directly by the impact of the pest and indirectly by the reduced competitive ability from lack of vigor of the crop with the weed host.

As knowledge and appreciation increases of the role of weed hosts as reservoirs for arthropods, nematodes, pathogens, and other organisms affecting crops, changes will occur in the ranking of the major weed problems. It may not occur that the criterion of a weed as a host will be the prime consideration, over competition (interference), in ranking the weediness of a plant species, but it is hoped that it will be one of the criteria of consideration. The weed hosts as reservoirs concept is a practical application of integrated crop protection.

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SOME OBSERVATIONS ON THE ECOLOGICAL APPROACH FOR MANAGING WEEDS IN INDIAN SEMI-ARID TROPICAL AGROECOSYSTEMS

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ABSTRACT

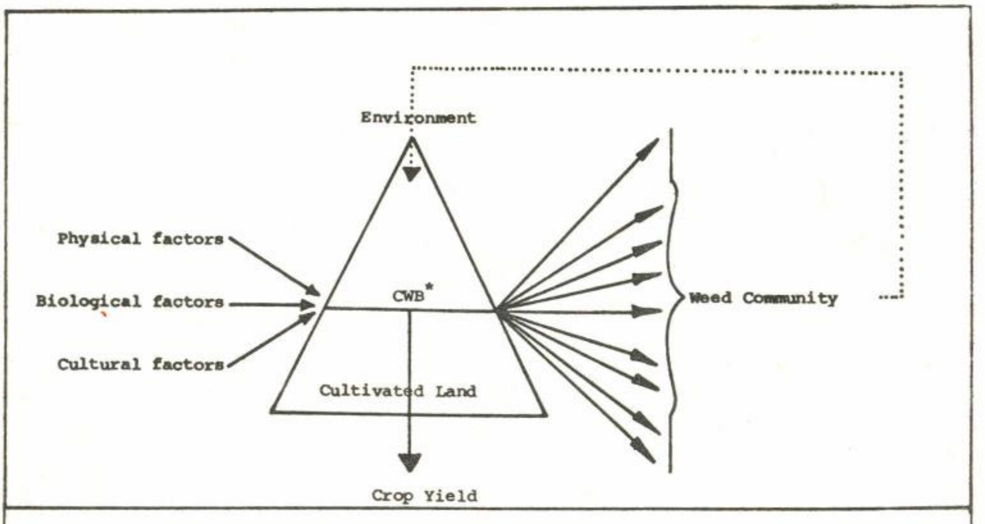
Weed growth was observed to be influenced by several cultural and biological factors. Weed growth associated with tall pearl millet cultivars was less than that with dwarf cultivars. With the increase in plant population pressure within the sorghum row, the intra row weed biomass was considerably decreased. The inclusion of an additional cowpea or mungbean suppressed weed infestation and virtually eliminated one hand weeding. The less weed growth under sorghum/cowpea and sorghum/mungbean intercropping systems was related to the less light available to the weeds. In pearl millet/groundnut system reduction in weed biomass was observed with the increase in pearl millet rows. Greater weed biomass was observed with high fertility levels suggesting that poor weed management with high fertilizer application would create an environment favorable to weeds. Study with pigeon pea revealed that environment detrimental to weeds could be created through selection of a competitive cultivar coupled with lower dosage of herbicide supplemented with a hand weeding. The preliminary observations thus revealed that many biological and cultural factors influence the weed growth and hence crop weed balance could be shifted in favor of crops by modifying the environment through identification of these factors.

INTRODUCTION

Within the terms of ecological framework, pests can be defined as those organisms that have surpassed man's tolerance levels in their exploitation of temporary habitats (agroecosystems) created by him to cultivate his crops. Among these pests, weeds need no definition as direct losses due to weeds are high because of the enormous cost and difficulty of effective control in existing crops and cropping systems.

Worldwide weed research has been mainly on herbicides. Although several herbicides are available, the setting in semi-arid tropical India does not permit full use of herbicides at least in the immediate future (Rao, 1977). The ecological approach to manage weeds aims at modifying the environment of agroecosystem in favor of crops through identification of the factors affecting the crop-weed balance and shifting the balance in favor of crops rather than to weeds (Rao, 1980).

Weeds did not arise spontaneously as a product of agriculture. The manipulation of physical, biological and cultural factors which are necessary for crop production favor one phytosociological class or weed community. The major cultural physical and biological factors influencing the crop weed balance are shown in Fig. 1. The interaction of cultural, physical and biological factors on the crop/weed growth determines the relative crop/weed balance. How cultural, physical and biological factors affect the weeds forms the basis for ecological approach for managing weeds. This basic knowledge on this would help us shift the balance in favor of the crop.



Physical factors	Biological factors	Cultural factors
1. Soil moisture	Crop type	Cropping Systems
2. Light intensity	Crop density	Cropping pattern
3. Temperature	Allelopathy	Fertilizer use
4. Basic soil fertility	Insect and disease problems	Tillage use
5. Rainfall		Chemical herbicides

*CWB: Crop Weed balance

Fig. 1: RELATIONSHIP BETWEEN PHYSICAL, BIOLOGICAL, AND CULTURAL FACTORS, WEED COMMUNITY AND CROP-WEED BALANCE.

A number of experiments were conducted at ICRISAT to assess the influence of biological (crop type, crop cultivar, crop density, allelopathy) and cultural (cropping systems, fertilizer ause and method of weed control) factors on weed community in terms of composition and competitiveness.

MATERIALS AND METHODS

The methodological approaches used in this study were the same as those reported by Shetty and Rao (1980).

RESULTS AND DISCUSSION

Effect of Biological Factors

Crop Cultivar

The results of an experiement involving 4 pearl millet cultivars (Fig. 2) revealed the superiority of the tall cultivars viz., Exbornu and IVS AX 75 to the dwarf cultivar Senegal dwarf synthetic weed growth. By selection of a higher yielding pearl millet cultivar with a tall growing habit and good foliage, the weed growth can be checked even with just one hand weeding. Cultivar selection being a low monetary input, would help the SAT farmer operate with small investment.

Crop density

Reduction in intra-row weed growth occured with the increase in intra-row crop density (Fig. 3a & 3b). In the present study the intra-row population was increased by widening the row width, while maintaining the total sorghum population constant. This manipulation of environment produced ecological niches for *Celosia* and *Digitaria* resulting in their greater biomass. These results indicate the need for a continuous ecological study to assess the possibility of any adaptive weed community becoming a threat in the long run due to adaptation of certain practices.

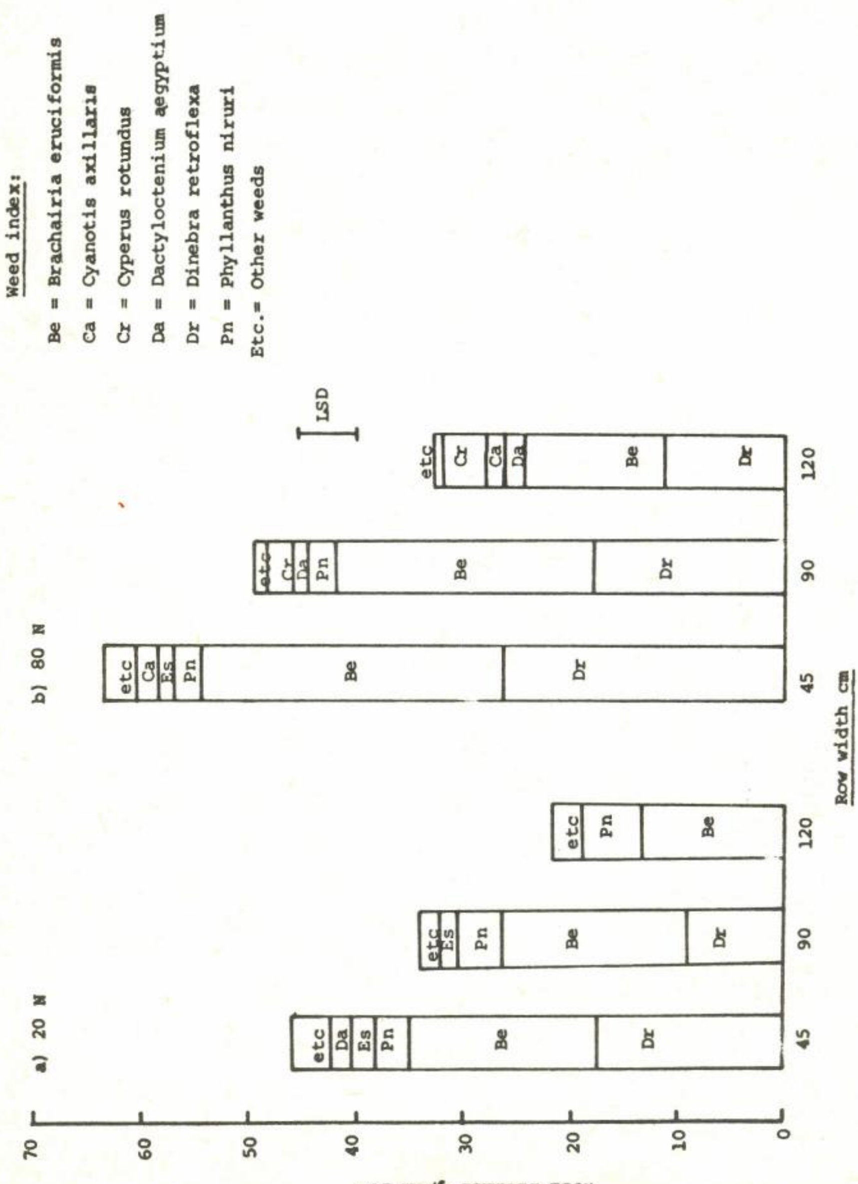


Fig. 3c. BIOMASS OF INDIVIDUAL INTRAROW WEEDS AT SORGHUM HARVEST AS AFFECTED BY CHANGE IN INTRAROW SORGHUM POPULATION MANIPULATED THRU, INCREASE IN ROW WIDTH AT TWO NITROGEN LEVELS. VERTISOLS, ICRISAT, 1978.

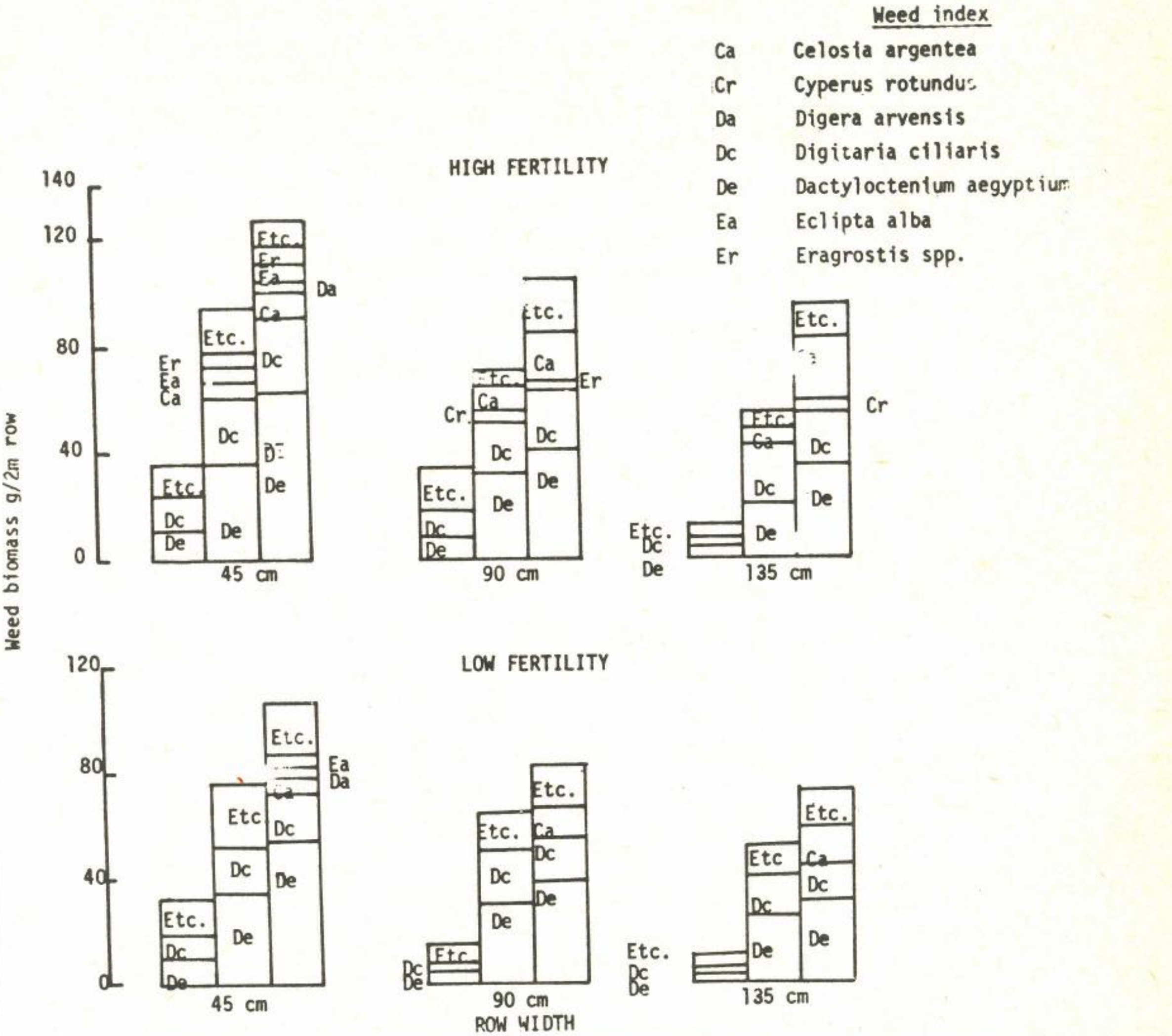


FIG 3b. BIOMASS OF CERTAIN DOMINATING INDIVIDUAL WEEDS AS AFFECTED BY INCREASING ROW WIDTH, ALFISOLS, ICRISAT, 1978

Cultural Factors

Cropping systems

Sorghum/cowpea and sorghum/mungbean intercropping system or "Smother" cropping system:

The inclusion of an additional crop of cowpea or mungbean showed promise in suppressing the weed infestation and virtually eliminated one hand weeding (Table 1). Thus the weed suppression due to this additional crop was about the same as that obtained with two hand weedings (Fig. 4). This inclusion of an additional smother crop has not only resulted in better weed suppression but also in additional yield from the smother crop. Grain yield data and net monetary returns also confirmed the superiority of the smother cropping system (Table 1). Net monetary returns from sorghum/cowpea (Rs. 3860) and sorghum/mungbean (Rs. 3684) obtained from one hand weeding treatment were considerably higher than the sorghum sole system given one hand weeding (Rs. 2398) or two hand weedings (Rs. 3389).

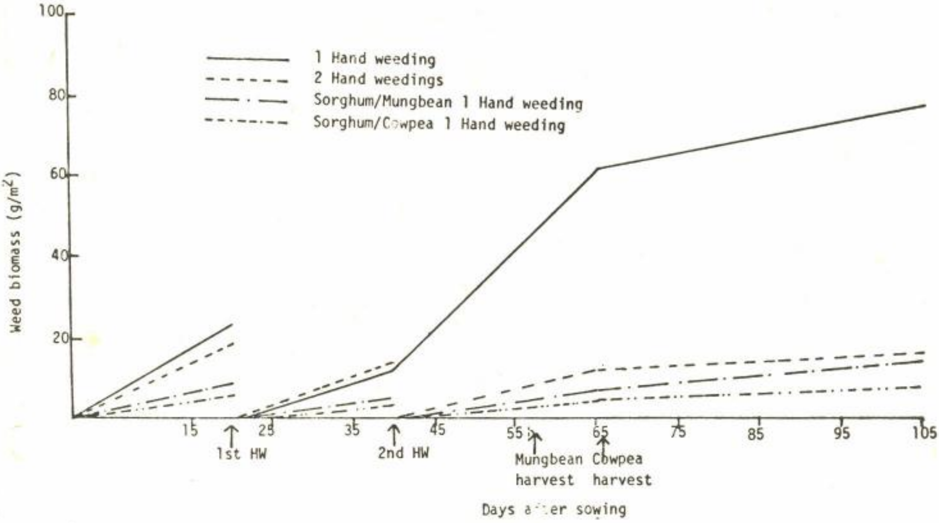


Fig.7; WEED GROWTH IN VARIOUS 'SMOTHER' CROPPING SYSTEMS UNDER DIFFERENT WEED MANAGEMENT SITUATIONS (ALFISOLS, 1979, RAINY SEASON

A detailed analysis of canopy development and pattern of light interception was conducted to understand the cophysiological mechanism behind the observed advantage of sorghum/cowpea and sorghum/mungbean smother cropping systems. Based on the light interception pattern (Fig. 5 and 6) and leaf area index (LAI) the inclusion of a smother crop viz., cowpea and mungbean results in quicker and earlier attenuation of maximum LAI and maximum percentage of light interception by component crops. Significant positive correlation was observed between LAI and percentage light interception. (Significant negative correlation was observed between percentage light interception by component crops and weed biomass accumulation.

Pearl millet/groundnut system (PM: GN system)

In this PM : GN system the weed biomass increased with an increase in the number of groundnut rows. The minimum and maximum weed biomass were observed with pearl millet sole and PM : GN (1 : 6) system respectively. The rapid increase in weed dry weights resulted from the introduction of more rows of groundnut which was a poor competitor. There was likewise an increase in density and biomass of *Celosia* and *Digitaria* with the increase in the groundnut rows. A better weed management practice which is more suited to manage these weeds should form

Table 1: *Grain yield of sorghum and smother crop and net production in terms of grain products monetary value. (Alfisols, 1979, Rainy season, ICRISAT).*

	Sorghum		Cowpea kg/ha	Mungbeen kg/ha	Weed dry matter at harvets gm2	Total pro- (Rs/ha)	Net pro- (Rs/ha)
	Grain yield	Stoover yield					
Sorghum + 1 Hand weeding	3652	4660	—	—	78.71	2418.50	396.50
Sorghum + 2 Hand weedings	5264	6958	—	—	16.97	3629.04	3389.40
Sorghum/Cowpea + 1 Hand weeding	4895	6083	223.81	—	8.30	4049.00	3869.00
Sorghum/mungbean + 1 Hand weeding	4952	6136	—	173.10	14.70	3936.18	3784.00
Sorghum, weed free	6408	7637	350.20	—	—	4416.00	393.00
Sorghum/cowpea weed free	6142	7237	350.20	—	—	5286.60	486.60
Sorghum/mungbean weed free	6183	7360	—	281.10	—	5104.20	4712.20
LSD at 5%	391	534.2	—	—	.727		

* *Considered monetary values Sogrhum 1 g — Rs. 69/-Cowpea 1 q = Rs. 300-, Mungbean 1 q as 3000/*

** *Net production = Total production = Hand weeding cost (Rs. 120/- each weeding) and "Smother crop seed cost (Cowpea Rs. 60/ha., Mungbean Rs. 32/ah).*

a part of an improved management technology for a pearl millet/groundnut intercrop.

These two studies on intercropping systems indicated that intercropping can be method of weed management if suitable component crops are grown with proper agronomic manipulation. Although not all the intercrop systems are favorable for weed suppression, some systems can be manipulated to obtain better weed management.

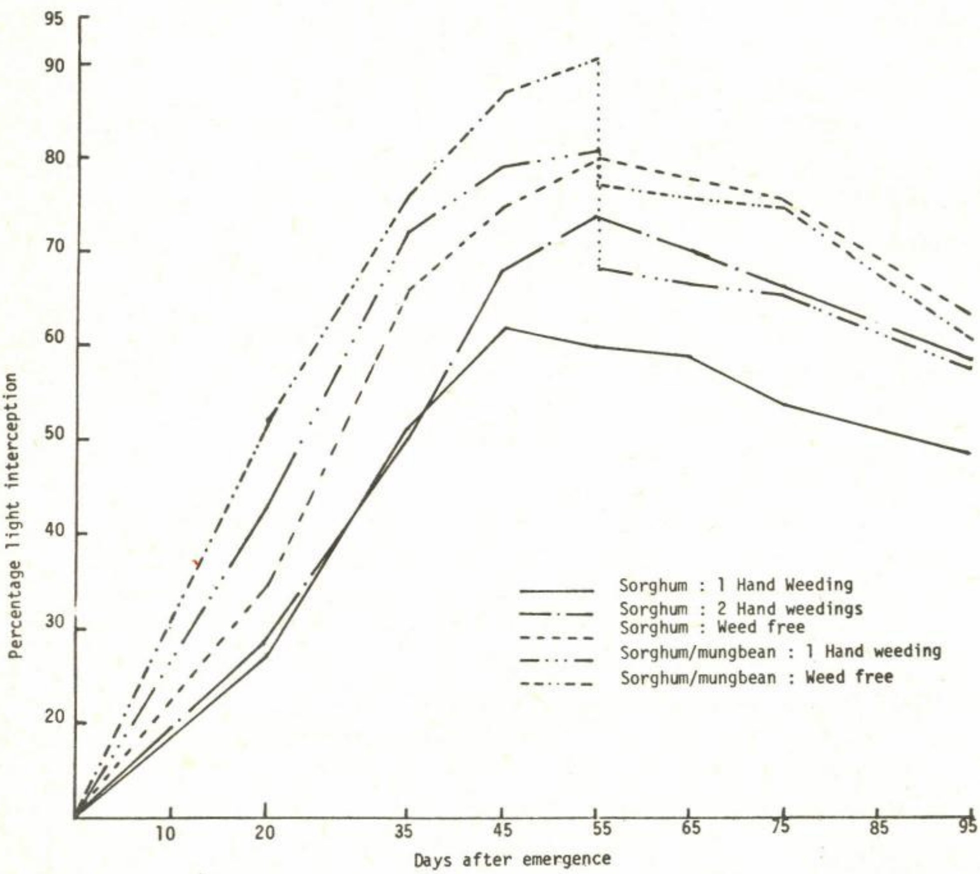


Fig 5. LIGHT INTEPCEPTION BY SORGHUM BASED SMOTHER CROPPING SYSTEMS UNDER DIFFERENT WEED MANAGEMENTS, ALFISOLS, 1979 RAINY SEASON.

Fertilizer usage

More weed growth was observed with high fertility levels (Table 2) suggesting that poor weed management with high fertilizer application would create an environment favorable to weeds. Thus fertilizer application and appropriate weed management should go together.

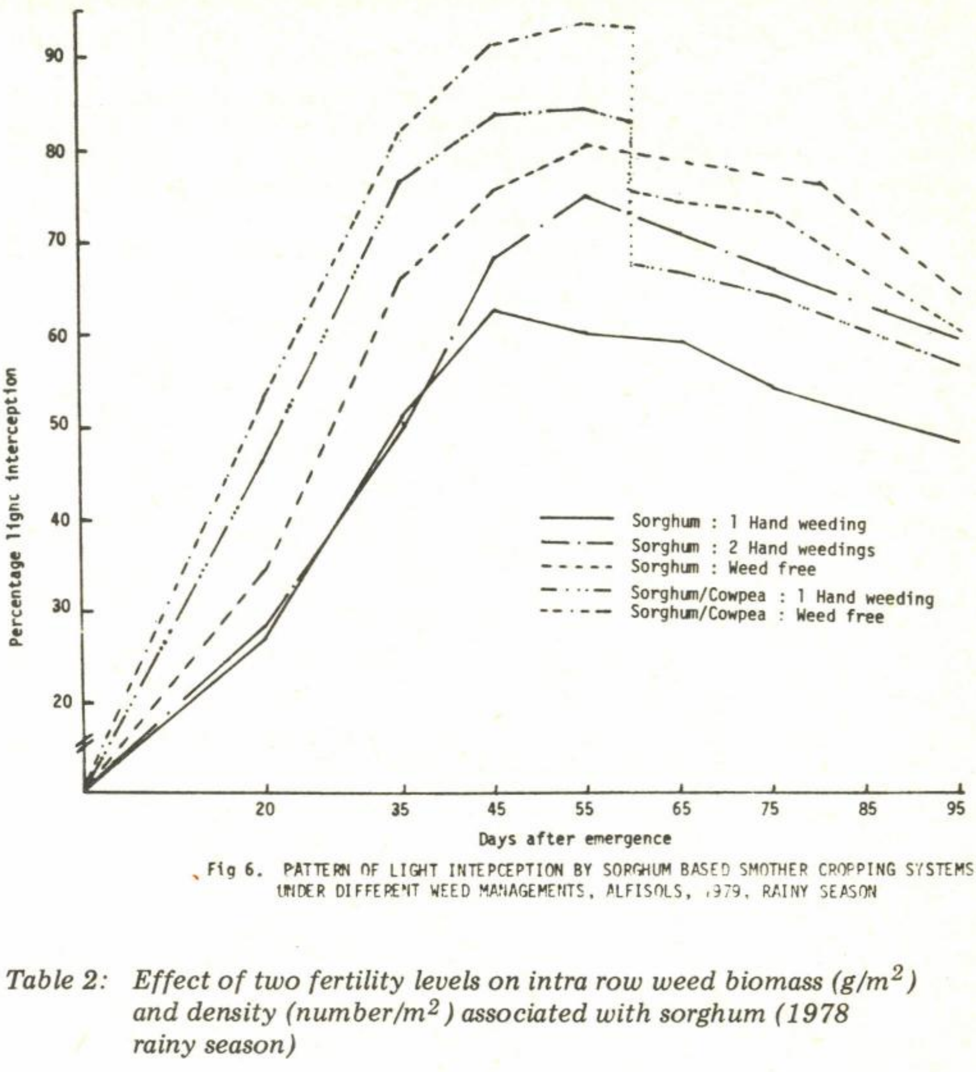


Fig 6. PATTERN OF LIGHT INTEPCEPTION BY SORGHUM BASED SMOTHER CROPPING SYSTEMS UNDER DIFFERENT WEED MANAGEMENTS, ALFISOLS, 1979, RAINY SEASON

Table 2: Effect of two fertility levels on intra row weed biomass (g/m^2) and density ($number/m^2$) associated with sorghum (1978 rainy season)

		High fetrility		Low fertility	
		Alfisols	Vertisols	Alfisols	Vertisols
Biomass	30th day	27.5	9.03	17.8	5.8
($/g/m^2$)	60th day	72.8		63.9	
	100th day	108.7	48.6	86.9	33.7
Density	30th day	83.8	58.5	78.2	49.9
(No/m^2)	60yh day	133.9		109.8	
	100th day	190.5	129.3	151.9	119.4

Method of weed control — usage of lower dosage of herbicide supplemented with hand weeding.

Use of high doses of herbicides, in addition to higher cost, would result in herbicidal pollution of agroecosystems either through pollen damage Dubey, 1977) or through toxic effect of the residues to the crops grown in rotation (Rao and Dubey, 1980).

Combining a competitive cultivar with lower dosage of herbicide and supplemented with a hand weeding was tested with pigeonpea. The results (Table 3) indicated that among the piegonpea cultivars tested CV : C-11 was more competitive and allowed less weed dry matter accumulation. The two other next best cultivars in this regard were CV:1 Tal and CV: 7065 respectively. The selection of a competitive cultivar along with lower doses of pre-emergence herbicide, to control initial flush of weeds, supplemented with one hand weeding (if necessary) at appropriate later growth stage may result in an environment detrimental to weed growth and favorable to crops under Kharif conditions. Such a manipulation of environment is difficult by complete hand weeding as it is impossible to enter the clay loams soils of the field, during earlier critical periods of crop weed competition especially under heavy rainfall situation that exists under Indian semi-arid tropical environment.

Table 3: Cumulative mean effect of pigeonpea cultivars and methods of weed control on weed density (Number/m^2) and biomass (g/m^2) (Vertisols 1978, rainy season)

Pigeonpea	At 1st HW		At 2nd HW		At harvest	
	Density	Biomass	Density	Biomass	Density	Biomass
7065	226.13	56.73	249.43	113.1	305.76	186.0
7086	163.93	76.66	337.43	168.56	381.0	314.93
Pusa ageti	196.1	62.4	349.56	135.53	387.0	277.89
1 — Tall	119.4	49.3	255.6	92.6	296.0	160.93
NP — 69	190.73	63.93	308.76	120.46	305.66	214.13
C — 11	185.26	46.13	258.7	81.3	447.0	139.1
Treatments						
Nitrogen	63.36	21.28	206.5	58.26	183.98	122.45
2 HW	207.9	76.93	79.05	69.4	175.25	140.51
Weedy check	269.5	79.36	594.2	228.11	619.0	397.33
LSD at 5%	25.29	26.91	12.71	5.88	24.79	21.86

Thus the overall results clearly indicate that certain biological factors like crop cultivar, crop density and cultural factors like intercropping systems and method of weed control have detrimental effect on weed growth. Thus by adapting the ecological approach of managing weeds which aims at identifying the factors and modifying the environmental in favor of crop, the crop weed balance could be shifted in favor of the crop through the manipulation of factors operating the agroecosystem.

Adaptation of the ecological approach discussed above and development of appropriate weed management systems utilizing this approach for different situations under different agroclimatological situations of India is possible through the inclusion and testing of the factors discussed here and identification of a few other factors detrimental to weeds through intensified weed ecology research.

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MIXTURES OF BUTACHLOR WITH NAPROANILIDE AND PYRAZOLATE FOR PERENNIAL WEED CONTROL IN IRRIGATED TRANSPLANTED RICE

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ABSTRACT

Field experiements were conducted to evaluage the performance of butachlor (N- (butoxymethyl)-2-chloro-2, 6-diethylacetanilide) formulations to gether with naproanilide (2-(napththoxy-N, N-diethylpropionamide) and pyrazolate (4-2(2,4-dichlorobenzoy 1)-1, 3-dimethylpyrazol-5-yl-p-toluenesulphonate) for effective control of perennial weeds in irrigated transplanted rice (*Oryza sativa* L.). Both butachlor-naproanilide and butachlor-pyrazolate at all rates and times of application studied gave adequate weed control of *Sagittaria pygmaea* Miq., *Potamogeton distinctus* A. Bennett and *Cyperus serotinus* Korsh. and yields of treated plots were significantly higher than the untreated check. However, they failed to control *Eleocharis kuroguwai* Ohwi.

Although a significant decrease in plant height was observed when rice was treated with butachlor-naproanilide at 1.6-2.4 kg/ha to 2.4-3.6 kg/ha 2 days after transplanting (DAT) yield was unaffected. Reduced rates of butachlor-naproanilide (0.8-1.2 kg/ha) and butachlor-pyrazolate (0.7-1.2 kg/ha) could be recommended for control of perennial weeds except *E. kuroguwai* when applied between 2 and 8 DAT.

INTRODUCTION

Intensive and continual use of herbicides for controlling annual weeds in irrigated transplanted rice fields in Korea has caused shifts in weed population, resulting in increase in population of perennial weeds (Ahn et al., 1976). A survey of the weed population by Kim *et al.* (1975) revealed that perennial weeds accounted for about 30% of the total weeds. Six years later, however, the percent distribution had reached 56% (Oh et al, 1981). This is a problem with respect to weed management since perennial weeds grow and infest new areas very rapidly and are relatively tolerant to the herbicides being used in this country.

Herbicides are often mixed to improve weed control without increasing the amount or the cost of the chemicals used. Ryang et al. (1981) reported that butachlor-naproanilide provided good weed control of several perennial weeds occurring in lowland rice areas. Pyrazolate also appeared to be promising for controlling perennial weeds.

This experiment was aimed at evaluating butachlor-naproanilide and butachlor-pyrazolate formulations for effective control of perennial weeds in irrigated transplanted rice at different rates and times of application.

MATERIALS AND METHODS

Two experiements were conducted at the experimental farm of Jeonbug National University, Jeonju, Korea in 1982. The first and second experiments consisted of sixteen treatments with butachlor-naproanilide and butachlor-pyrazolate, respectively (Tables 1 and 2). The herbicide mixtures were formulated on the same carrier and applied as a single treatment.

The experiments were carried out on a clay loam soil with pH 6.1, organic matter 2.3%, and CEC 14 meq/100g. A randomized complete block design with three replications was used. Plots were 15 m^2. To ensure a uniform weed population twenty tubers (or bulbs) of the perennial weeds were sown in each plot 1 day before transplanting. The perennial weed species were *S. pygmaea*, *P. distinctus*, *C. serotinus*, and *E. kuroguwai*. Seedlings of Iri 346 were machine-transplanted at the three to four-leaf-stage. Hand weeding was done at 20 and 40 DAT. One hundred fifty kg/ha of nitrogen was applied in equal splits, basally, at maximum tillering, and at panicle initiation while P_2O_5 (100 kg/ha) and K_2O (120 kg/ha) were applied as basal applications. Insect control and other cultural practices were at optimum levels.

For rice, plant height and tiller number were determined 40 DAT. The dry weight of weeds was measured 40 DAT from 5 m^2 sample areas. Grain yields were determined by harvesting 5 m^2 areas and adjusting the moisture content of the cleaned grains to 14%.

RESULTS AND DISCUSSION

In both experiments, the important annual weeds were *Echinochloa crus-galli* (l.) Beauv., *Monochoria vaginalis* (Burm. f.) Presl., *Rotala indica* Koehn., and *Lindernia procumbens* Philcox. All herbicide treatments gave excellent weed control of the annual weeds except naproanilide alone which could not kill completely *E. crus-galli* (data not shown).

Effect of butachlor-naproanilide. Butachlor-naproanilide treatments except those applied at 0.8-1.2 kg/ha controlled *S. pygmaea*, *P. distinctus* and *C. serotinus* adequately, but they failed to control *E. kuroguwai* (Table 1). The effect of weed control did not significantly vary with the time of application.

Table 1. Effect of butachlor-naproanilide formulation on perennial weed control and growth and yield of irrigated transplanted rice (Iri 346). Means within a column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

Herbicide treatment	Application		Weed weight (g/m^2)				Plant height (cm)	Tiller number (No./hill)	Yield (t/ha)
	Rate (kg a.i./ha)	Time (DAT)	*Sagittaria pygmaea*	*Potamogeton distinctus*	*Cyperus serotinus*	*Eleocharis kuroguwai*			
Hand-weeded check	—	—	1.2a	2.3a	1.6ab	1.7a	44.8a	27.2a	7.1a
Butachlor —Naproanilide	0.8-1.2	2	3.4a	5.6a	2.8ab	4.8a	43.9a	26.4ab	7.0a
Butachlor —Naproanilide	0.8-1.2	5	3.6a	5.0a	3.0ab	4.4a	43.9a	26.3ab	7.0a
Butachlor —Naproanilide	0.8-1.2	8	3.8a	5.0a	3.0ab	3.8a	45.3a	26.7a	6.9a
Butachlor —Naproanilide	1.2-1.8	2	2.0a	4.4a	1.8ab	3.4a	43.0ab	26.1ab	7.1a
Butachlor —Naproanilide	1.2-1.8	5	2.4a	4.4a	2.4ab	3.6a	43.5a	27.5a	7.0a
Butachlor —Naproanilide	1.2-1.8	8	2.0a	5.0a	2.8ab	3.2a	44.4a	26.9a	7.0a
Butachlor —Naproanilide	1.6-2.4	2	1.0a	4.2a	1.0ab	2.6a	41.2b	26.4ab	7.0a
Butachlor —Naproanilide	1.6-2.4	5	1.0a	3.8a	1.4ab	2.8a	42.1ab	27.2a	7.1a
Butachlor —Naproanilide	1.6-2.4	8	1.4a	4.2a	2.0ab	2.4a	43.5a	26.9a	7.0a
Butachlor —Naproanilide	2.4-3.6	2	0.4a	3.4a	0.8a	2.2a	40.8b	25.9ab	6.9a
Butachlor —Naproanilide	2.4-3.6	5	0.4a	3.3a	1.2ab	2.4a	42.1ab	26.4ab	6.9a
Butachlor —Naproanilide	2.4-3.6	8	0.6a	3.8a	1.6ab	2.6a	42.2ab	26.9a	6.9a
Butachlor	1.8	5	9.1b	5.0a	3.4b	4.4a	44.4a	25.8ab	6.4ab
Naproanilide	3.0	5	1.6a	5.0a	3.2ab	4.6a	42.6ab	26.4ab	6.5ab
Untreated check	—	—	12.6b	10.1b	7.2c	7.0a	41.7b	22.5b	5.8b

Table 2. Effect of butachlor-pyrazolate formulation on perennial weed control and growth and yield of irrigated transplanted rice (Iri 346) Means within a column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

Herbicide treatment	Application		Weed weight (g/m^2)				Plant height (cm)	Tiller number (No./hill)	Yield (t/ha)
	Rate (kg a.i./ha)	Time (DAT)	*Sagittaria pygmaea*	*Potamogeton distinctus*	*Cyperus serotinus*	*Eleocharis kuroguwai*			
Hand-weeded check	—	—	0a	0a	0.4a	3.7a	45.7a	27.0a	7.0a
Butachlor —Pyrazolate	0.7-1.2	2	1.4a	0a	1.2a	4.8a	43.9a	26.9a	7.1a
Butachlor —Pyrazolate	0.7-1.2	5	1.4a	0a	0.6a	3.8a	46.2a	27.2a	7.1a
Butachlor —Pyrazolate	0.7-1.2	8	1.8a	0a	1.0a	3.8a	46.1a	26.1ab	7.0a
Butachlor —Pyrazolate	1.08-1.8	2	0.8a	0a	0a	2.6a	44.8a	27.5a	6.7ab
Butachlor —Pyrazolate	1.08-1.8	5	0.4a	0a	0a	2.6a	45.3a	28.0a	7.0a
Butachlor —Prazolate	1.08-1.8	8	1.0a	0a	0a	3.0a	45.3a	28.0a	7.1a
Butachlor —Pyrazolate	1.4-2.4	2	0.4a	0a	0a	2.2a	42.6a	26.7ab	7.1a
Butachlor —Pyrazolate	1.4-2.4	5	0.2a	0a	0a	2.0a	44.4a	27.5a	7.0a
Butachlor —Pyrazolate	1.4-2.4	8	0.4a	0a	0a	2.2a	45.3a	27.5a	6.8ab
Butachlor —Pyrazolate	2.1-3.6	2	0a	0a	0a	2.0a	42.6a	26.4ab	6.8abb
Butachlor —Pyrazolate	2.1-3.6	5	0a	0a	0a	2.1a	43.0a	27.2a	7.1a
Butachlor —Prazolate	2.1-3.6	8	0a	0a	0a	1.8a	44.8a	27.5a	7.0a
Butachlor	1.8	5	8.0b	7.3b	5.6b	5.1a	43.0a	26.4ab	6.1bc
Pyrazolate	3.0	5	0.4a	0a	0.8a	3.8a	46.2a	27.5a	6.8ab
Untreated check	—	—	15.2c	8.4b	6.4b	4.2a	43.9a	23.4b	5.6c

Plant height of rice was not significantly affected by butachlor-naproanilide at all rates tested when applied 5 and 8 DAT, while a significant decrease in plant height was observed with butachlor-naproanilide at 1.6-2.4 to 2.4-3.6 kg/ha 2 DAT. On the other hand, there was no significant difference in tiller number between the rates and times of application studied. All herbicide formulations gave yields significantly higher than the yield of the untreated check. Yields did not vary significantly between the rates and times of butachlor-naproanilide application.

Effect of butachlor-pyrazolate. All formulations together with butachlor or pyrazolate alone provided excellent weed control of the annual weeds (data not shown). When butachlor-pyrazolate or pyrazolate alone was applied, excellent weed control of *S. pygmaea*, *P. distinctus* and *C. serotinus* was obtained, irrespective of the rates and times of application used (Table 2). However, butachlor applied alone failed to give adequate weed control of the perennial weeds. All the herbicide treatments performed poorly in controlling *E. kuroguwai.*

All the herbicide treatments were completely safe to the crop as measured by plant height and tiller number. Yields of plots treated with butachlor-pyrazolate and pyrazolate alone were significantly higher than the yield of the untreated check. Yield reduction in the butachlor-treated plot was due to high incidence of perennial weeds.

When naproanilide was formulated with butachlor, Takematsu and Konnai (1978) reported that the effect of the formulation on weed control increased and appeared in a short time compared with when naproanilide alone was used. The formulation usually shows relatively high toxicity to rice when applied prior to transplanting (Ryang *et al.*, 1981). The toxic effect is due primarily to butachlor (Takematsu and Konnai, 1978). As shown in this experiment, the amount of butachlor and naproanilide can be reduced without any adverse effect with respect to weed control of perennial weeds and crop injury when they are formulated together. On the other hand, pyrazolate at 3 kg/ha as a single treatment is recommended to control effectively perennial weeds in transplanted rice (Sankyo Co., 1980). The reduced rate of 1.2 kg/ha when combined with butachlor performed equally well as the recommended rate of pyrazolate alone. Moreover, the treatment made prior to transplanting does not result in a decrease in weeding effect nor an increase in crop injury (Ryang *et al.*, 1981). However, mixtures of butachlor with naproanilide and pyrazolate cannot control *E. kuroguwai.*

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EVALUATION OF OXYFLUORFEN IN PREGERMINATED BROADCAST LOWLAND RICE IN SRI LANKA

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ABSTRACT

Field trials were conducted in 1981 and 1982 to evaluate the efficacy of oxyfluorfen for weed control in broadcast lowland rice (*Oryza sativa* L.). Oxyfluorfen at 0.12 to 0.15 kg/ha gave appreciable control of the predominant weeds, *Echinochloa spp.* and *Cyperus spp.* Early application (3 to 5 DAS) of oxyfluorfen was better than late application (6 to 8 DAS). There was considerable increase in grain yields in plots treated with oxyfluorfen compared to those of propanil treated and unweeded plots.

INTRODUCTION

Rice is grown in 0.65 million hectares in Sri Lanka, 85% of which is cultivated as lowland rice. More than 80% of lowland rice culture is done by direct sowing of pregerminated seeds in puddled soil. For the establishment of rice seedlings in direct-seeded rice, water has to be drained off. This allows the germination of rice and weeds simultaneously, making it very difficult to handweed at the seedling stage (Gunasena, 1971). Failure to control weeds during the first three weeks after seeding reduces rice yield by fifty percent (Jayasekhara and Velmuruga, 1966).

Chemical weed control is usually practiced in Sri Lanka for weed control in direct-seeded lowland rice.Propanil (3,4-dichloro-propionanilide) and MCPA (4-chloro-2-methoxyphenyl acetic acid) are widely used. Because both are postemergence herbicides, it is essential to drain off water and expose the weeds and for maximum efficiency as to 5 to 6 hours of dry weather after spraying is necessary for effective weed control by these herbicides. Thereafter, continuous submergence has to be maintained to prevent further weed germination. The time of herbicide application is also critical as herbicides are most effective at certain stages of growth (Gunasena, 1971). These conditions are rarely met. The Maha season (October to March) coincides with heavy monsoon rains and in Yala season (April to Sept.) it is very difficult to maintain adequate water level throughout crop growth (Table 1). Propanil controls grasses whereas MCPA is effective against sedges and broadleaf weeds only. Usually the weed population in direct-seeded lowland rice in Sri Lanka includes grasses, sedges and broadleaves. Hence application of either Propanil or MCPA alone finds inadequate weed control. On the other hand, using both is expensive in addition to the fact that they have to be sprayed at two different times.

Oxyfluorfen (2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluormethyl benzene) is a selective, contact, broad-spectrum preemergence herbicides. All India coordinated Rice Improvement Project (AICRIP) trials (Anonymous, 1980) indicated that oxyfluorfen at 0.10 to 0.15 kg/ha controlled grasses, sedges and broadleaves in direct-seeded lowland rice in India. This study was then conducted to test the efficacy of oxyfluorfen for weed control in direct-seeded lowland rice.

Table 1: Monthly rainfall at Mahailluppalama, Sri Lanka

	Rainfall					
Month	1977	1978	1979	1980	1981	1982
January	35.96	12.16	3.64	0.08	22.84	0.00
February	15.64	17.32	9.16	0.00	4.20	0.00
March	15.64	17.36	5.84	19.08	14.24	38.96
April	77.12	39.28	46.32	66.64	79.12	45.92
May	47.08	75.44	11.72	44.64	32.48	65.16
June	0.96	0.00	1.48	16.36	2.92	6.92
July	11.06	44.36	6.96	0.28	36.44	0.56
August	43.36	0.20	1.52	4.20	26.64	1.88
September	36.08	11.24	55.16	76.96	46.08	16.08
October	210.00	119.48	116.28	71.64	74.68	106.02
November	109.02	221.84	111.06	168.08	78.44	97.32
December	57.28	90.36	51.08	62.24	49.28	0.00
TOTAL	660.84	649.08	421.48	531.72	468.08	378.82

MATERIALS AND METHODS

The trials were conducted in North-Central Province of Sri Lanka in farmers fields during the 1981 Maha and Yala season. Pre-germinated rice seeds were broadcast in puddled and levelled plots at the rate of 80 kg/ha. Oxyfluorfen (EC) was mixed in uniform dry sand and broadcast in the plots at the rate of 60 kg/ha on saturated soil surface. The plots were irrigated 2 to 3 days after chemical application. From 10 to 12 days after sowing (DAS) water level was maintained. Propanil was sprayed 10 DAS as recommended.

Toxicity ratings were taken one week after herbicide application. Weed counts were taken from 0.5 m^2 quadrats at three locations for each plot at 30 and 60 days after sowing. Grain yield was also recorded. In one trial weed matter was taken at the flowering stage of the weeds (60 DAS).

RESULTS AND DISCUSSION

Oxyfluorfen at 0.12 to 0.15 kg/ha did not cause any seedling mortality. Injury ratings at these rates were comparable with those for the standard propanil treatments (Table 2). However, crop injury due to oxyfluorfen increased with rate. Crop injury was less when oxyfluorfen was applied at 6 to 8 DAS as compared to application at 3 to 5 DAS (Table 3).

Phytotoxicity symptoms of oxyfluorfen on rice were characterized by yellowing of lower leaves at 3 to 4 days after application. The new leaves that emerged later were not affected. Seedling mortality was less than 2 to 4 percent. At 0.21 kg/ha slight stunting was observed.

The predominant weeds were *Echinochloa* spp. and *Cyperus* spp. in both trials. Oxyfluorfen controlled both *Echinochloa* spp. and *Cyperus* spp. effectively whereas propanil did not control *Cyperus* spp (Table 2). Application of oxyfluorfen 3 to 5 DAS gave better weed control than when applied 6 to 8 DAS (Table 3). Considerable number of weeds have already germinated at 6 to 8 DAS. As oxyfluorfen is a preemergence herbicide, it could not control those weeds that have already germinated. Hence poor weed control was obtained when it was applied at 6 to 8 DAS as compared to application at 3 to 5 DAS.

Herbicide treatments gave significantly higher yields as compared to the unweeded control treatments. In the 1981 trial, oxyfluorfen at 0.12 and 0.15 kg/ha yielded significantly better than propanil and the higher rates of oxyfluorfen (Table 2). This agrees with the results of IACRIP, where oxyfluorfen at the rate of 0.15 kg/ha applied at 6 DAS gave better weed control and grain yield (Anonymous 1980). Higher rates of oxyfluorfen (0.21 kg/ha) gave poor yields.

Table 2. Effect of herbicide treatments on crop injury, weed number and grain yield of rice during the 1981 Maha season.

Herbicide	(kg/ha)	Toxicity rating[1]	No. of weeds/m *Echinocloa spp*	No. of weeds/m *Cyperus spp*	Grain yield (kg/ha)
Oxyfluorfen 5 DAS	0.09	0.50	51	31	4750
Oxyfluorfen 5 DAS	0.12	0.75	32	21	5700
Oxyfluorfen 5 DAS	0.15	1.00	31	20	5650
Oxyfluorfen 5 DAS	0.18	1.50	20	16	5250
Oxyfluorfen 5 DAS	0.21	2.00	11	5	4750
Propanil	3.50	0.75	42	80	4900
Unweeded control	–	0.00	155	112	4050
S.EM	–	–	10	14	199
C.D.O.	.05	–	22	31	434

[1]Toxicity Scale: 0-No Injury, 10-Complete Kill

Application of oxyfluorfen at 3 to 5 DAS gave better grain yield than later applications (6 to 8 DAS) and the propanil treatments (Table 3). Early application effectively controlled weeds such that even a very low dose of 0.06 kg/ha was comparable to propanil at 3.5 kg/ha and oxyfluorfen at 0.18 kg/ha. Similar results were obtained by the Rice Research Station, Maha Illuppalama, Sri Lanka (Anonymous, 1982).

During the Maha season (main rice growing season) the monsoon is very active. Rainfall is quite heavy during October and November and rice is planted during these months. Several times it is very difficult to get one or two rain free days to allow postemergence herbicide application. A pre-emergence herbicide which is least soluble in water will be more suitable in this situation. Oxyfluorfen fulfills this requirement as its solubility is less than 0.1 ppm in water at 25 C. This was also one reason for its superior performance to propanil.

Table 3. Effect of herbicide treatments on crop injury, weed dry matter and grain yield of rice during the 1982 Yala season.

Treatments	Rate (kg/ha)	Toxicity rating	Dry wt. of weeds (g/m^2)	Grain yield (kg/ha)
Oxyfluorfen 3-5 DAS	0.06	0.50	59.3	5233
Oxyfluorfen 3-5 DAS	0.12	1.00	20.0	5562
Oxyfluorfen 3-5 DAS	0.18	1.50	12.3	5458
Oxyfluorfen 6-8 DAS	0.06	0.00	97.0	4828
Oxyfluorfen 6-8 DAS	0.12	0.50	81.7	4915
Oxyfluorfen 6-8 DAS	0.18	1.00	81.3	5152
Propanil	3.50	1.00	49.3	5050
Unweeded control	–	0.00	215.0	3650
	S.Em	–	8.8	122
	C.D O. 05	–	18.9	262

[1]Toxicity rating scale: 0 = no injury; 10 = complete kill

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EFFECT OF CHEMICAL AND CULTURAL WEED CONTROL METHODS ON YIELD OF DRILLED RICE

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ABSTRACT

Different rates of butachlor and thiobencarb alone and in combination with one manual weeding at 45 days after sowing were evaluated for weed control in drilled rice *(Oryza sativa L.)*. Uncontrolled weeds, on the average, resulted in more than 97% reduction in the grain yield of rice. Butachlor provided better weed control than thiobencarb, but was more phytotoxic to rice than thiobencarb. Higher yields were obtained with higher rates of herbicides. Herbicide application supplemented with one manual weeding at 45 days after sowing increased weed control efficacy resulting in yields higher than when herbicides were applied alone. Thiobencarb at 1.5 and 2.0 kg/ha combined with weeding 45 days after sowing gave yields comparable to treatments which were kept weed-free throughout the cropping season.

INTRODUCTION

Direct seeding of rice under unpuddled condition, either by broadcast or drilling (upland rice) is a common practice of rice cultivation in India. About 22.5 million ha are planted to upland rice (Dixshit, 1974) where yields are extremely low. Upland rice largely accounts for the low average yield of rice in the country Singh, 1978). Poor weed control is considered to be a major reason for the low yield of drilled rice.

The problem posed by weeds in drilled rice is severe. Weeds emerge simultaneously with the emerging crop seedlings and grow luxuriantly thereby resulting in intense competition with the crop. Yield losses in drilled rice due to uncontrolled weeds have been reported to be 40 to 80%, and in many cases there have been complete crop failures due to heavy weed infestation (Pandey and Bhan, 1966; Mukhopadhyay *et al.*, 1972; AICRPWC, 1980, 1981).

Weed control in drilled rice may be accomplished by mechanical means, by the use of herbicides, or by a combination of both. Manual weeding is the common practice in drilled rice. This is possible only when the weeds have attained certain stature. By that time damage has already been done to the crop. Because operation has to be repeated, the availability of labor is also a problem especially if needed on a large scale during peak periods of farm operations. At present, no herbicide is available for safe, economical and efficient control of a wide spectrum of weeds in drilled rice. Manual weeding can not be dispensed with at present under Indian conditions as it is an important component of the weed control program. Similarly, herbicides seem to be essential for the weed control system to be effective in drilled rice. This study was then carried out to develop weed control measures for drilled rice using a combination of cultural and chemical methods.

MATERIALS AND METHODS

The study was carried out during the monsoon season of 1981 at two locations at the Crop Research Center, G.B. Pant University of Agriculture and Technology, Pantnagar (Nainital), India. The soil at site 1 was silty clay loam (14.9% sand, 58.4% silt, 26.3% clay, 1.13% organic matter). It had a phosphorus content of 50.2 kg P/ha and potassium content of 228.2 kg K/ha, and a pH of 7.7. The soil at site 2 was a loam (38.4% sand, 45.2% silt, 16.4% clay, 0.58% organic matter), with a phosphorus content of 109 kg P/ha, potassium content of 109.0 kg K/ha and a pH of 7.7.

The mean maximum and minimum temperatures during the two cropping seasons ranged between 26.7 to 34.1^{o}C and 13.7 to 25.9^{o}C, respectively. The total rainfall received throughout the season was 661.4 mm, most of which was received during July. The average relative humidity varied from 60 to 90%.

The experiments at both sites were laid out in a randomized complete block design with four replications. Treatments consisted of three rates each of butachlor [2-chloro-2', 6'-dietyl-N (methoxy methyl) acetanilide and thiobencarb [S(4-chlorophenyl)-methyl-diethylcarbamothioate] alone and in combination with one manual weeding at 45 days after sowing (DAS), two weeaings at 15 and 45 DAS, weeding at 45 DAS, and the weed free and weedy checks (Table 1). EC formulations of both herbicides were used. Butachlor was applied at 1 DAS while thiobencarb was applied at 6 DAS. Rice cv Pusa 2-21 was sown in the last week of June 1981 at site 1 and in the first week of July, 1981 at site 2 with a fertiseed-drill at 100 kg seed/ha and a row spacing of 23 cm. Recommended cultural practices were followed to maintain optimum crop growth.

RESULTS AND DISCUSSION

Echinochloa colona (L.) Link, *Cyperus iria* L., *Scirpus grossus* L. and *Trianthema monogyna* L. were the major weed species at both sites. *E. colona* and *C. iria* constituted 47.8 and 27.4% of the total weed population, and 33.9 and 37.4% of the total weed dry matter production, respectively, at 30 days after seeding in weedy check plots.

Butachlor and thiobencarb at all rates caused a significant reduction in weed dry weight and density at different stages of crop growth (Tables 1 and 2). Higher rates of butachlor resulted in significantly less weed weights and densities as compared to the lower rates throughout the cropping season. This observation was prominent at 45 and 75 DAS with both herbicides. At 15 DAS such effects were not much apparent due to the short period between the time of herbicide application and the time of observation. Thiobencarb at 1.5 and 2.0 kg/ha produced significantly less weed dry weights than at 1.0 kg/ha.

A follow-up of one manual weeding at 45 DAS after herbicide application resulted in further reduction in weed density and dry weight at subsequent stages (Tables 1 and 2). This was due to reduced weed regrowth after hand weeding and increased competitive ability of the crop at this stage. Such effects were more pronounced at the higher rates of both herbicides. Weeding at 15 DAS did not give adequate weed control.

Table 1. Number of weeds/m^2 at different stages of crop growth as affected by chemical and cultural control methods. Weeding was done at 45 DAS except when specified.

Treatment	Rate (kg/ha)	15 D A S		45 D A S		75 D A S	
		Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Butachlor	1.0	94	109	134	146	128	157
Butachlor	2.0	46	67	38	43	59	62
Butachlor	3.0	14	11	24	32	30	43
Butachlor + weeding	1.0	104	112	160	178	8	16
Butachlor + weeding	2.0	46	56	80	88	4	9
Butachlor + weeding	3.0	28	30	22	19	0	2
Thiobencarb	1.0	248	296	338	409	209	317
Thiobencarb	1.5	250	241	262	248	178	150
Thiobencarb	2.0	127	132	216	207	112	117
Thiobencarb + weeding	1.0	285	301	367	397	4	8
Thiobencarb + weeding	1.5	166	175	260	286	0	3
Thiobencarb + weeding	2.0	84	75	231	252	0	0
Weeding 15 and 45 DAS	–	430	656	293	308	0	3
Weeding 45 D A S	–	622	662	583	607	0	2
Weed-free	–	00	00	00	00	0	0
Weedy	–	572	679	598	611	486	535
L.S.D. (0.05)		28	31	26	29	15	17

Butachlor was generally more effective than thiobencarb in reducing weed density and dry weight throughout the cropping season. Weed growth was fastest during the first 45 DAS and declined at later stages.

Table 2. Dry weight of weeds (g/m^2) at different stages of crop growth as affected by cultural and chemical control methods. Weeding was done at 45 DAS except when specified.

Treatment	Rate Kg/ha	15 DAS		45 DAS		75 DAS	
		Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Butachlor	1.0	6.1	8.2	140.6	149.8	509.3	587.2
Butachlor	2.0	2.8	3.6	46.9	52.1	346.2	364.3
Butachlor	3.0	1.7	2.8	30.3	24.2	148.2	158.7
Butachlor + weeding	1.0	5.5	7.6	142.1	140.2	33.8	42.3
Butachlor + weeding	2.0	2.4	3.2	75.3	85.1	21.4	29.8
Butachlor + weeding	3.0	1.4	1.5	29.8	33.2	00	0.1
Thiobencarb	1.0	7.7	9.5	228.7	301.1	495.2	507.6
Thiobencarb	1.5	5.7	6.2	172.4	192.7	389.3	412.1
Thiobencarb	2.0	4.4	5.1	143.8	156.3	371.4	407.2
Thiobencarb + weeding	1.0	5.7	8.5	272.5	299.8	00	0.3
Thiobencarb + weeding	1.5	4.9	6.7	156.2	167.2	00	0.2
Thiobencarb + weeding	2.0	2.5	5.2	140.6	142.1	00	00
Weeding 15 and 45 DAS	–	10.9	12.2	133.7	144.3	00	0.1
Weeding 45 DAS	–	9.7	11.3	409.5	500.1	00	00
Weed-free	–	00	00	00	00	00	00
Weedy	–	11.4	12.1	413.6	512.1	682.4	693.0
L.S.D. (0.05)	–	1.1	1.3	33.7	30.6	31.1	29.8

At 15 to 45 DAS, the dry matter produced by the crop in butachlor-treated plots was significantly lower than all other treatments due to butachlor phytotoxicity especially at the nighest rate (Table 3). However, at 75 DAS, butachlor at 1 kg/ha produced less dry matter of crop than the higher rates shift due to poor weed control at the lower rates. Dry matter of crop in thiobencarb-treated plots during 15 DAS was slightly lower than that in weed free plots due to slight phytotoxicity of thiobencarb. At later stages thiobencarb at 1.5 and 2.0 kg/ha produced more crop dry matter than at 1.0 kg/ha. In general, dry matter of crop in thobencarb-treated plots was higher than those in butachlor-treated plots.

Butachlor and thiobencarb treatments supplemented with one or two weedings at 15 and 45 DAS resulted in better crop growth than herbicide application alone (Table 3). Weeds in weedy check plots had no adverse effect on the crop during the first 15 days of crop growth. At the later stages however, there was a drastic reduction in the crop dry matter due to heavy crop-weed competition. Panicle number was reduced drastically in the weedy check plots due to competition with weeds. resulting in 94.9% and 99.2% reduction in the grain yield at site 1 and site 2, respectively (Table 4). Grain weight was affected significantly due to crop-weed competition in weedy plots at site 1 but not at site 2. All treatments produced higher grain yield, more panicles and grains per panicle than the weedy check because of reduced crop-weed competition. Thiobencarb at 2.0 kg/ha followed by weeding at 45 DAS at both sites, weeding at 15 and 45 DAS at site 1, and

Table 3. Dry matter of crop (g/m^2) at different stages of crop growth as affected by chemical and cultural control methods. Weeding was done at 45 DAS except when specified.

Treatment	Rate kg/ha	15 DAS Site 1	15 DAS Site 2	45 DAS Site 1	45 DAS Site 2	75 DAS Site 1	75 DAS Site 2
Butachlor	1.0	5.4	4.2	93.3	84.7	417.1	389.7
Butachlor	2.0	3.8	3.1	93.3	83.2	478.1	398.2
Butachlor	3.0	2.9	2.8	84.0	76.3	444.3	404.2
Butachlor + Weeding	1.0	5.7	4.3	93.8	81.2	515.4	509.2
Butachlor + Weeding	2.0	3.8	3.6	89.9	83.7	534.7	499.7
Butachlor + Weeding	3.0	3.0	3.1	81.9	78.2	480.2	470.2
Thiobencarb	1.0	7.9	7.2	99.0	90.2	417.2	405.3
Thiobencarb	1.5	7.9	7.6	106.4	105.8	461.4	448.7
Thobencarb	2.0	7.1	6.9	111.0	114.2	469.8	444.2
Thiobencarb + Weeding	1.0	7.7	7.5	96.8	101.2	507.7	498.2
Thiobencarb + Weeding	1.5	8.0	7.9	110.8	115.3	512.5	488.2
Thiobencarb + Weeding	2.0	8.0	8.2	113.1	118.7	604.7	590.2
Weeding 15 and 45 DAS	–	8.4	8.0	119.5	111.2	595.8	585.3
Weeding 45 DAS	–	8.0	7.8	86.5	109.3	417.8	401.3
Weed-free	–	9.3	8.7	125.5	120.4	660.1	622.7
Weedy	–	9.0	9.2	83.1	74.5	180.2	165.2
L.S.D. (0.05)		1.2	1.3	4.9	5.2	12.6	15.2

Table 4. Grain yield, number of panicles, number of grains/panicle and 1000 grain weight of rice treated with herbicides alone and in combination with handweeding. Weeding was done at 45 DAS except when specified.

Treatment	Rate kg/ha	Grain Yield (kg/ha) Site 1	Grain Yield (kg/ha) Site 2	No. of panicles/m row length Site 1	No. of panicles/m row length Site 2	No. of grains/panicle Site 1	No. of grains/panicle Site 2	1000-grain weight (g) Site 1	1000-grain weight (g) Site 2
Butachlor	1.0	2.62	0.96	80	72	55	52	19.3	19.4
Butachlor	2.0	4.04	3.50	84	80	63	62	20.3	19.3
Butachlor	3.0	3.14	3.64	82	79	57	54	20.6	19.5
Butachlor + Weeding	1.0	5.18	2.33	92	82	67	63	20.7	20.1
Butachlor + Weeding	2.0	5.24	4.37	93	90	69	67	20.9	20.6
Butachlor + Weeding	3.0	3.50	4.49	88	87	63	65	20.6	20.7
Thiobencarb	1.0	2.43	1.34	75	70	53	49	18.7	19.6
Thiobencarb	1.5	3.29	3.01	82	84	56	57	19.9	19.2
Thiobencarb	2.0	3.56	3.35	82	83	58	60	20.2	19.7
Thiobencarb + Weeding	1.0	4.98	4.43	89	87	64	67	20.0	20.1
Thiobencarb + Weeding	1.5	5.13	4.79	92	90	62	59	20.9	19.6
Thiobencarb + Weeding	2.0	5.72	4.90	96	94	73	70	21.5	20.7
Weeding 15 and 45 DAS	–	5.56	4.56	93	90	69	72	21.4	20.5
Weeding 45 DAS	–	2.71	2.75	81	82	46	52	18.1	19.2
Weed-free	–	5.76	5.06	96	91	72	79	21.9	19.8
Weedy	–	0.29	0.04	47	32	28	22	17.9	19.2
L.S.D. (0.05)		0.27	0.29	15	13	12	11	1.6	N S

thiobencarb at 1.5 kg/ha at site 2 produced grain yields which were comparable to the weed-free treatments. No significant differences between grain yields obtained with thiobencarb at 1.5 kg/ha followed by weeding at 45 DAS and thiobencarb at 2.0 kg/ha followed weeding at 45 DAS at site 2.

Higher rates of butachlor and thiobencarb produced greater grain yields. Weeding at 45 DAS following application of both herbicides resulted in a significant increase in grain yields over the application of herbicides alone. This increase in grain yield was associated with comparatively more panicles and grains per panicle due to supplementary weeding. This was more distinct at the lower rates that at the higher rates. The low degree of weed control at the lower rates caused supplementary weeding to result in higher yield increases. At site 1, butachlor at 1.0 and 2.0 kg/ha followed by weeding 45 DAS, and thiobencarb at 1.0 and 1.5 kg/ha followed by weeding 45 DAS produced comparable grain yields, number of panicles, and number of grains per panicle. However, at site 2, butachlor at 1.0 kg/ha followed by weeding at 45 DAS produced grain yield which was significantly less than that at the higher rates supplemented with one weeding at 45 days. This was a result of less panicles and grains per panicle in this treatment due to higher weed density at site 2.

Grain yield in plots weeded at 45 DAS was 52.9% of that in weed-free plots at site 1 and 45.6% at site 2. Weed competition during the first 45 days of crop growth on average, resulted in 49.2% reduction in grain yield. Number of panicles and number of grains per panicle were also affected due to crop weed competition during this period. The differences between the grain yields of weeding 15 and 45 DAS, and weeding 45 DAS suggest that one weeding at 15 DAS may be equal to application of butachlor or thiobencarb at 1.0 kg/ha. In general, grain yields, irrespective of treatments, were less at site 2 than at site 1 due to high weed density at site 2.

ACKNOWLEDGEMENTS

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WEED GROWTH IN UPLAND RICE AS AFFECTED BY WEED CONTROL TREATMENTS

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ABSTRACT

Field experiments were carried out to study the effect of herbicides on the growth of associated weeds and yield of direct seeded upland rice (*Oryza sativa* L.). The major weed population in the experimental field consisted of broadleaf annuals (*Phyllanthus niruri* L., *Ammonia baccifera* L.), grass annuals (*Echinochloa colona* (L.) Link, and *Echinochloa crus-galli* L. Beauv.). Propanil (3',4-dichloropropionanilide) was found most effective against grasses and sedges, whereas butachlor (2-chloro-2',6'-diethyl-N-(butoxymethyl acetanilide), (L and G, was more effective against broadleaf weeds. In the phenoxy group, MCPA (2-methyl-4-chlorophenoxyacetic acid) was found most effective against sedges. Propanil and butachlor (L and G) reduced weed competition and produced higher grain yield. 2,4-dichlorophenoxyacetic acid (2,4-D) and MCPA were most ineffective and caused more weed dry matter accumulation throughout the crop growth period. Experimental year 1979 was drought year (438 mm rain) but weed growth was more than the year 1980 (1111.00 mm rainfall).

INTRODUCTION

Rice is the most popular crop of India. It is grown in an area of 42.0 million hectares (Anonymous, 1981). Out of these approximately 70% is under upland condition which is entirely dependent upon rainfall. Rice under this condition is grown mostly by direct seeding method. Among the various factors responsible for the low yields of rice in Indian agriculture, weeds are of major importance. Various workers have estimated 10 to 70% loss due to weeds (Mani *et al.*, 1968; Pillai *et al.*, 1976). The magnitude of losses varies with the kind and intensity of weed flora, and rate of dry matter accumulation. Sharma *et al.* (1977) reported that rice yield was minimum when the field was infested with weeds up to maturity.

Growth analysis has been established as a standard method of estimating photosynthate production of plant stands. The net photosynthate production of weeds is affected by many factors related to uncertain monsoon weather. It is commonly observed that under upland rice culture, weather provides more congenial atmosphere for growth of weeds. In this paper an attempt was made to analyze the weed flora and their growth as affected by different herbicide treatments.

MATERIALS AND METHODS

The experiment was conducted with rice [(*Oryza sativa* cv Cauvery (IET 355)] during summer monsoon seasons of 1979 and 1980 at the research farm of Banaras Hindu University, Varnasi. The weed control treatments consisted of four pre-emergence herbicides and four post-emergence herbicides and four postemergence herbicides. The pre-emergence herbicides were butachlor (as liquid Machete or L 50% EC) at 2.0 kg/ha and the granular butachlor (Machete 5% G at 1.0 kg/ha), and granular 2,4-D (4% W/V granules) at 1.0 kg/ha. The three postemergence herbicides were liquid 2,4-D (Weedar L-96 72% AE) at 1.0 kg/ha), thiobencarb (S-(4-chlorobenzyl) N,N-diethylthiolcarbamate), and propanil (Stam F-34 35% EC at 2.0 kg ai/ha. Hand weeding at 20, 40, and 60 days and unweeded control were also included for comparison. Rice seeds were sown in rows 25 cm apart at 100 kg/ha. Fertilizer was applied at the rate of 120 kg/ha nitrogen, 26 kg/ha phosphorus and 50 kg/ha potash in each year. Half of the nitrogen and all the phosphorus and potassium were applied basally at last plowing before sowing and the remainder of nitrogen in two equal dosages at tillering and panicle initiation stages. Preemergence and postemergence herbicides were applied at 4 and 20 days after sowing respectively. Liquid formulations were sprayed with a foot sprayer and granules were broadcast after mixing with dry soil. Meteorological data were recorded monthly during the crop growing season. Weed composition, dry matter accumulation, and yield were recorded. Absolute growth rate (AGR) was calculated using the formula of Watson (1952).

RESULTS AND DISCUSSION

Weed Composition. Relative composition of weed flora under different treatments are given in Table 1.

Herbicide effect. The effectivity of different herbicides on grasses, sedges, and broadleaf weeds indicated that butachlor (G) and propanil were most effective against grasses and broadleaf weeds, which were the predominant flora (Table 2). As a result, maximum reduction of weed was observed in these treatments. Favorable effect of these herbicides against grasses and broadleaf weeds has been also reported by Nair *et al.*,(1974).

Growth Rate and Yield. Dry matter accumulation and absolute growth rate of weeds indicate differential response to herbicides and season (Table 3). Herbicides, butachlor (L and G) and propanil were superior to the other herbicides, because these herbicides reduced dry matter accumulation and absolute growth rate (AGR). Similar findings have been reported by Pillai and Rao (1974). In general, pre-emergence application of herbicides had maximum growth inhibition of weeds during early stages, whereas, postemergence herbicide had maximum growth inhibition at later stages except propanil which had a consistently better effect during a longer period of crop growth. The differential effect of herbicides can be explained in light of pre-emergence herbicides that persisted only 4 to 6 weeks after application (Kulshrestha *et al.*, 1981); postemergence herbicides lasted up to later stages of growth as it was applied 20 days after seeding. The results (Table 3) envisage that treatments, hand weeding, propanil, butachlor (L and G) and benthiocarb had lower weed population, dry matter accumulation and AGR values during early stages of crop growth and resulted in very high yield, whereas the presence of weeds during early stages resulted in yield losses which reflected a progressive influence of early competition. Seasonal variations had a distinct effect on the growth and AGR values of weeds. During 1979, the AGR values increased at the early stages of growth but decreased later. Dry matter accumulation increased at 45, 75 and 105 days of growth, while, during 1980 a decreasing pattern was observed up to 75 days of duration. Thereafter dry matter accumulation and AGR values increased up to maturity.

Table 1. Weed composition in the rice field.

Weed species	Scientific name	% composition	
		1979	1980
Grasses	*Echinochloa colona* (L.) Link	15.10	14.10
	Cynodon dactylon (L.C. Rich) Pers.	7.10	6.60
	Echinochloa crusgalli (L.) Beauv.	2.00	2.20
	Others	2.88	3.64
Sedges	*Cyperus rotundus* L.	13.54	12.62
	Fimbristylis milliaceae (L.) Vahl	12.60	13.10
	Others	2.46	3.53
Broadleaves	*Phyllanthus niruri* L.	20.45	22.50
	Ammania baccifera L.	6.00	5.00
	Caesulia axillaris	4.20	3.40
	Corchorus acutangulus Lam.	4.00	3.30
	Commelina benghalensis L.	3.00	2.10
	Eclipta alba (L.) Hassk	2.30	2.00
	Euphorbia hirta L.	2.00	1.10
	Others	2.37	4.81

The possible reason for increased growth rate in 1979 was the limited rainfall of 438 mm received during the crop season which adversely affected the crop but favorably affected weed growth. Adverse weather conditions, e.g. drought, temperature, rainfall, humidity intensified the cropweed competition interference in favor of the weeds. Results are in confirmity

Table 2. Effect of herbicides on relative composition of weed flora.

	Grasses		Sedges		Broad Leaves		Total		% Reduction Based on Control	
Treatments	1979	1980	1979	1980	1979	1980	1979	1980	1979	1980
Control	109.6	103.3	78.3	76.6	111.8	106.0	299.7	285.9	–	–
Hand Weeded	6.0	4.6	17.3	16.3	30.1	28.0	53.4	48.9	82.18	82.8
Butachlor, Liquid	38.1	34.0	61.3	56.6	54.6	48.0	154.0	138.6	48.6	51.5
Butachlor, Granular	35.1	31.6	34.4	32.7	51.3	46.6	120.8	110.9	59.6	61.2
Propanil	35.4	32.0	21.5	18.8	59.3	56.3	116.2	107.1	61.2	62.2
Benthiocarb	44.0	41.3	56.0	58.6	62.3	58.0	162.3	157.9	45.8	44.7
Nitrofen	51.6	48.0	44.0	42.6	85.3	85.0	180.9	175.6	39.6	38.5
2,4-D, Liquid	79.3	75.3	58.0	57.0	76.6	75.6	213.9	207.9	28.6	27.2
2,4-D, Granular	82.6	78.3	70.0	68.1	74.6	71.0	227.2	217.4	24.2	23.9
MCPA	80.6	76.3	44.6	43.6	95.6	94.0	220.8	213.9	26.3	25.2
(P = 0.05)	7.0	9.4	9.4	11.3	5.2	6.5				

Table 3. Effect of herbicides on dry matter accumulation and absolute growth rate of weeds and grain yield.

Treatments	Rate (kg/ha)	Dry Matter Accumulation (g/m^2)										Pooled grain yield (quintal/ha)
		45 days		75 days		105 days		45-75 days		75-105 days		
		1979	1980	1979	1980	1979	1980	1979	1980	1979	1980	
Unweeded control	–	263.4	340.1	418.4	280.1	381.4	303.8	1.83	−1.9	1.23	0.78	7.13
Hand weeded	–	40.1	43.7	48.5	35.2	50.2	42.4	0.28	−0.27	0.06	0.23	26.87
Butachlor (L)	2	116.9	134.4	138.4	113.5	154.3	121.3	0.71	−0.69	0.53	0.25	18.00
Butachlor (G)	1	116.1	139.1	137.7	119.1	151.1	126.5	0.72	0.66	0.44	0.24	17.83
Propanil	2	153.5	167.8	167.1	140.2	175.0	145.9	0.45	0.91	0.26	0.18	16.62
Thiobencarb	2	153.4	175.5	176.1	150.9	119.0	158.1	0.77	0.82	0.48	0.23	16.14
Nitrofen	2	161.9	163.5	167.1	158.8	197.0	165.8	0.17	0.16	0.99	0.23	17.83
2,4-D (L)	1	246.4	271.1	276.8	238.3	288.9	245.2	1.02	1.09	0.40	0.23	10.16
2,4-D (G)	1	252.1	280.4	280.9	242.1	287.2	249.3	0.96	1.28	0.20	0.24	9.29
MCPA	1	245.3	269.4	270.5	235.2	280.2	141.8	0.83	1.14	0.32	0.22	10.54
(P = 0.05)		4.87	6.64	15.0	15.0	21.89	24.0					4.83

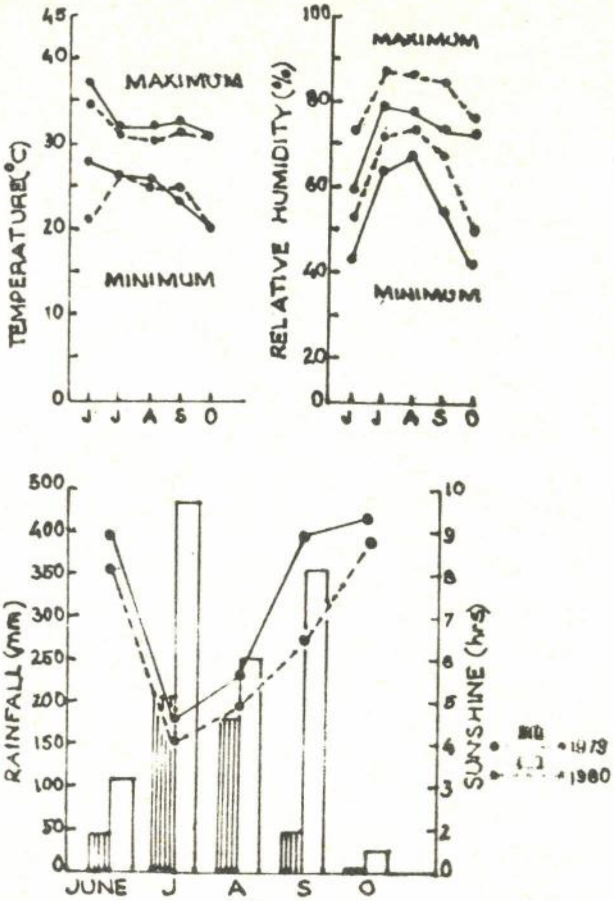

Fig. 1. Meteorological data for the experimental period.

with the findings of Maiti (1977) that vegetation correlates well with the meteorological conditions such as temperature, rainfall and humidity.

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WEED CONTROL IN TRANSPLANTED RICE IN KHARAGPUR, INDIA

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ABSTRACT

Two field experiments were conducted on chemical, manual and mechanical methods of weed control in transplanted rice to find the most suitable and economical method. Grain yield from treatments with piperophos [S-2-methyl-1-piperidyl-carbonyl-methyl)-0, 0-di-N-propyl dithiophosphate + dimethametryne (2-(1',2'-dimethyl-propylamine)-4-ethylamino-6-methylmercopto-S-triazine), butachlor (2-chloro-2',6'-diethyl-N-(butoxymethyl) acetanilide, thiobencarb (3-(4-chlorobenzyl) N,N-diethylthilcarbamate), and propanil (3',4'-dichloropropionanilide and two hand weedings did not show any appreciable variation. In the integrated approach, application of butachlor or propanil followed by weeding by rotary weeder or hand-weeding was found to be as effective as two hand weedings. The increase in grain yield was to the extent of 47.40% over unweeded control. Propanil at 2 kg/ha proved to be most economical and gave RS 2264.46/ha(US $226.5/ha) additional profit over control. This was followed by propanil + weeding by rotary weeder + hand weeding, and butachlor + weeding by rotary weeder + hand weeding in that order.

INTRODUCTION

Yield reduction in transplanted rice due to weeds is found to be from 5 to 72% (Pillai, 1977; Smith *et al.*, 1977; Shahi *et al.*, 1979; Akobundu, 1980; De Datta, 1980; Singh and Biswas, 1981 and Kolhe *et al.*, 1982). De Datta (1980) reported that the losses caused by weeds in potential production of rice was estimated to be 11.8% in Asia, about 10.0% in India and 5.9% in the world. It is thus apparent that any field measure, adopted or developed to control weeds, would eventually minimize the loss in production. Chemicals alone are often found effective against weeds only for a certain period of crop growth and weeds may reoccur. Moreover, repeated application at frequent intervals is not only costly but may also prove toxic. This study therefore, was conducted to determine the effect of using combinations of weed control methods in the control of problem weeds in transplanted rice.

MATERIALS AND METHODS

Two experiments were conducted under farmers' field condition at Balarampur during wet season of three consecutive years 1979, 1980 and

1981. The soil properties of the experimental site are given in Table 1. In Experiment 1, four herbicides were compared with hand weedings as well as hoeings. This was conducted for two consecutive years 1979 and 1980. In Experiment 2, which was conducted during 1981, three methods of weed control — chemical, manual and mechanical were tried singly as well as in combination. Among the four herbicides tested only butachlor was used in two formulations namely granular and EC. In all the experiments a late maturing (about 145 days) rice cultivar, Pankaj, was transplanted at 20 cm row to row and plant to plant spacing. The experiments were laid out in randomized block design with three replications. The herbicides used were piperophos + dimethametryne, butachlor, thiobencarb and propanil. The first three were applied as preemergence at 3 days after transplanting (DAT), while the last one was applied as post-emergence at 20 DAT. All the herbicies were applied at 2.0 kg/ha. In experiment 1, the crop was fertilized with 100, 50, 50 kg NPK/ha, while in Experiment 2, it was 60, 30 kg NPK/ha, Nitrogen was applied in three splits of 50% at transplanting, 25% at tillering and the remaining 25% at flowering. Phosphorus and potassium were applied as basal fertilizers at transplanting. The nitrogen removed by weeds and taken up by crop were determined by micro Kjeldahl method at harvest.

RESULTS AND DISCUSSION

The rice crop was mainly infested with *Alternanthera sessilis* (L.) Dc., *Commelina benghalensis* L., *Cynodon dactylon* (L.C. rich) Pers., *Cyperus difformis* L., *Cyperus iria* L., *Echinochloa colona* (L.) Link., *Echinochloa crus-galli* (l.) Beauv., *Fimbristylis miliacea* (l.) Vahl., *Hydrolea zeylanica* (l.) Vahl., *Lindernia ciliata* (Colsm.) Perrell, *Ludwigia perennis* L., *Marsilia quadrifolia* L., *Oldenlandia corymbosa* L. and *Polygonum pleibium* R. Br.

Experiment 1

Preemergence application of piperophos + dimethametryne (Avirosan), and post-emergence application of propanil caused significant reduction in crop-weed competition (Table 2). Their effect was comparable to two hand weedings or two hoeings at 20 and 40 DAT. Avirosan gave the lowest weed dry matter but this was not reflected on the yield. There was significant increase in grain yield as well as yield components namely number of panicles/m^2 and number of grains per panicle. A significant negative correlation of r = 0.949 and r= —0.910 was observed between dry matter of weeds and grain yield during 1979 and 1980 respectively. This clearly indicated that early control of weeds could minimize weed infestation and thereby competition. As a result, the crop growth and finally the production of panicles/m^2 as well as grains per panicle increased. Increase in these two major yield components, increased the grain yield. In case of propanil, maximum number of panicles/m^2 and number of grains per panicle and thereby grain yield of 63.88 q/ha was recorded. This was followed by butachlor (G) with 63.16 q/ha, butachlor (EC) with 61.07 q/ha, thiobencarb with 58.16 q/ha and Avirosan with 57.45 q/ha in order. However, all the herbicides were

Table 2. Effect of different methods of weed control on rice grain yield and dry matter of weeds.

Treatment	No. of panicles/m ^{2}		No. of grains panicle		Test weight, g		Grain yield, q/ha		Dry matter of weeds, kg/ha	
	1979	1980	1979	1980	1979	1980	1979	1980	1979	1980
Avirosan	293.67	269.79	114.27	74.68	25.12	24.03	60.90	54.00	10.81	12.10
Butachlor(G)	310.00	313.13	121.33	72.18	24.22	24.55	64.32	62.00	24.10	39.23
Butachlor(EC)	295.00	350.00	124.87	66.49	24.22	24.08	61.47	60.67	21.51	47.50
Thiobencarb	286.33	305.21	125.40	60.56	24.47	25.95	62.31	54.00	16.47	19.82
Propanil	313.33	362.50	143.67	78.56	25.83	26.35	71.43	55.33	13.21	56.50
Two Hand weedings*	229.67	277.09	115.60	81.59	25.69	24.61	64.04	43.33	12.24	59.83
Two Hoeings*	279.00	272.92	125.00	79.41	24.95	25.87	60.91	42.00	22.48	95.67
Unweeded control	257.00	245.84	106.00	57.88	23.76	24.38	37.57	33.67	215.01	186.40
LSD (P=0.05)	9.31	51.04	10.44	7.94	—	—	12.85	9.07	23.90	57.26

*At 20 and 40 DAT

found to be comparable in controlling the weeds and increasing the grain yield of the crop. The grain yield under different herbicide treatments was significantly higher than two hand weedings as well as two hoeings. Butachlor applied as granular (G) or liquid (EC) proved to be equally effective. Similar findings were also reported by Eastin (1981), Shahi et al (1979); Miller et al., (1981); Richard et al, (1981) and Kolhe et al (1982).

Table 1. Physical and chemical properties of the soil in the experimental site.

Particulars		Specific Details
Major soil group Laterite		
Mechanical composition		
Coarse sand,	%	25.72 to 33.53
Fine sand,	%	18.78 to 25.82
Silt,	%	20.94 to 26.25
Clay,	%	19.63 to 28.75
Bulk density, g/cc		1.46 to 1.52
Textural class	Sandy – clay – loam	
Chemical properties		
pH		53. to 5.4
Organic carbon,	%	0.30 to 0.53
Available N,	%	0.041 to 0.045
Available P,	%	0.004 to 0.005
Available K,	%	0.030 to 0.069

Experiment 2

Among the various weeds observed, *A. sessilis, H. zeylanica, L. perennis. F. miliacea, E. colona* and *C. difformis* contributed 28.14, 21.09, 19.21, 17.02, 4.93, and 4.24 per cent of total dry matter of weeds respectively (Table 3). The reduction in dry matter of weeds was comparable under different weed control treatments. The early weed competition could be minimized by applying any of the weed control treatments. It is apparent from Table 4 that propanil controlled *E colona, C. dactylon, C. difformis, F. miliacea, O corymbosa, Rotala indica* (Will) Kochne, *A. sessilis* and *L. ciliata* most effectively. Butachlor, on the other hand, failed to control *C. dactylon, H. zeylanica* and *A. sessilis.*