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WEED MANAGEMENT: TOWARDS TOMORROW
(With Emphasis on the Asia-Pacific Region)

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Summary. The rapidly expanding population in developing countries in the Asia-Pacific region demands a greater supply of quality food and fibre. Weed specialists are facing the challenge of having to increase agricultural production and to satisfy social and environmental needs at the same time. We are persuaded to change and be creative in developing weed management tools that seek to optimize long-term farm productivity by balancing economic, social and environmental responsibilities. This is the goal of a proposed framework for weed management. Weeds and soil degradation are just two of the many facets that are interlinked within any farming system. Farmers also experience widely different socio-economic constraints that have a strong influence on their final decisions on weed management. The future will require weed specialists to adopt an integrated approach that can incorporate all these facets in solving the weed problems of tomorrow. A wide range of physical, chemical, biological and ecological methods are available for weed management. Technology such as herbicides will remain essential, but requires some adjustments. The balance with our social and environmental responsibilities is now being considered early in the design of new herbicide technology.

INTRODUCTION

The developed nations are scaling down agricultural production due to economic considerations such as overproduction. They have the luxury to do so because population growth is insignificant at 0.6% (7) and there is still, in general, an abundance of low-cost food and fibre. However, Asian nations cannot afford to scale down agricultural production because of the already large population base of 3000 million coupled with a relatively high growth rate of 1.9% (7). Furthermore, most of these nations depend substantially on a dynamic agriculture as the engine of economic growth for the immediate future (2, 21). Agricultural production is still critical in many areas because of unstable and low agricultural productivity, rapid loss of prime agricultural land to urbanization, and shortage of agricultural labour, especially in countries actively pursuing industrialization like those in South-East Asia.

As a consequence, developing countries in the Asia-Pacific region are facing a new challenge for the 21st century -- the need to increase agricultural production and, at the same time, to minimize the impact on the environment. This is the ultimate goal of agricultural sustainability (26). As weed specialists, our task in the past has been to communicate objective, scientific knowledge to the general public. Now, communication alone is insufficient to alleviate the fears arising from concerns over the risks associated with weed-control decisions on society and environment. Only by addressing these concerns early in our activities can we ensure that they will be manageable in the future. This paper discusses the common problems, especially soil degradation and weeds, that farmers are facing in developing countries in the Asia-Pacific region; promotes a model for weed management in line with economic, social and environmental goals; proposes a framework for weed management; and highlights the intervening methods available for the farmers.

AGRICULTURAL SYSTEMS AND CONSTRAINTS IN DEVELOPING COUNTRIES

Types of agriculture. Most of the developing Asia-Pacific region is characterized by a general sub-humid to humid climate. Within this climatic regime is a diversity of topography, weather patterns, soils, vegetation, crops, human geography, farming systems and socio-economic situations. About 60% of the total population in the region are farmers (7), of which 75% are small-scale farmers, scattering into a mosaic of millions of 0.5-5 ha farming units (2). In general, agriculture has evolved into three main types: subsistence, cash cropping (green revolution) and commercial systems (3). Most countries have a mixture of all three (Table 1). Some typical examples of subsistence, cash-cropping and commercial agriculture are the low-input maize/upland rice, high-input irrigated rice, and high-input oil palm or fruit tree system, respectively. Generally, rice dominates the agricultural scene in Asia while edible tubers, coconut and banana are the major crops in the Pacific.

Table 1. Types of agriculture in developing countries in the Asia-Pacific region; modified after Chambers *et al.* (3)

Descriptor	Subsistence	Cash cropping	Commercial
Main locations	Rain-fed upland (Indonesia, Philippines, Thailand, Laos, Vietnam, Myanmar, Sri Lanka, India, Pakistan)	Irrigated lowland, upland (Indonesia, Philippines, Thailand, Vietnam, China, Taiwan, Korea, Myanmar, Bangladesh, Sri Lanka, India, Malaysia)	Specilized upland areas (Indonesia, Philippines, China, Taiwan, Korea, Sri Lanka, Malaysia)
Type of farmers	Small-scale farmers (1000 million)	Small-scale to large-scale farmers	Plantation managers, commercial farmers
Farming system	Complex (shifting cultivation, cereal-based, mixed, agroforestry)	Simple (lowland rice-based, upland cereal-based, perennial cropping)	Simple (perennial cropping)
External inputs	Low	Moderate to high	High
Production risk	High (generally)	Moderate	Low

Constraints to agriculture. Farmers in the region face a number of physical, biological and socio-economic constraints. Their farming decisions are based on a complex interaction of these factors (Table 2). For instance, farmers who wish to purchase a technology (such as quality seeds, fertilizers or herbicides) that fits their goals and reduces production risk may be short of credit. They would have to depend on the available subsidies. The lower education level of the farmers means that the technology requires support from extension for it to be implemented appropriately. The entire decision-making process involves the interaction of seven potential socio-economic constraints.

The constraints to agriculture vary according to agricultural type, location and country but, in general, agricultural productivity depends largely on consistent crop yields, stable political systems and continuing rural development. Of all the farmers, the small-scale farmers have the greatest need for practical know-how and technologies to increase production. Appropriate technologies, together with extension services and the supply of agricultural inputs including the marketing and distribution channels, must be developed and strengthened.

Weeds and soil degradation. Irrespective of agricultural type, the two major physical and biological constraints to productive agriculture are soil degradation (mainly water and wind erosion) and high weed infestations (6, 8, 13, 22, 27). Direct costs of weed control in terms of both value and labour vary greatly depending on the location, crop, weed status, timing of weeding, and method used. With herbicides, the costs of weed control as a proportion of the total inputs is 13% in soybean in Thailand (24), 26% in young rubber, 28% in young oil palm and 34% in young cocoa in Malaysia (4). Manual weeding constitutes 26-198 man-day/ha, equivalent to 17-57% of the total labour used per cropping season in South-East Asia (Table 3). Manual weeding is highly labour intensive, inefficient and also costly especially in those countries experiencing a shortage of agricultural labour (12).

Table 2. Constraints to productive agriculture on a farm in developing countries in the Asia-Pacific region; modified after Beets (2)

Physical	Biological	Socio-economic	
		Internal	External
Climate	Planting materials	Family composition	Population growth
Soils	Livestock	Health and nutrition	Land tenure/farm size
Topography	Weeds	Education	Social infrastructure
Water	Pests	Food preferences	Credit
	Diseases	Risk aversion	Markets
		Attitudes/goals	Prices
		Gender relations	Technology
		Other occupations	Input supply/subsidies
			Extension
			Savings opportunity

A substantial proportion, 44% (167 million hectares) of the 379 million hectares of soils in the humid tropical Asia, are inherently acidic and infertile (18). The major group of these acidic poor soils is the 131 million hectares of Ultisols (35%), located in much of South-Fast Asia. In these acid soils, erosion is particularly severe in cleared forests due to shifting cultivation and an extensive conversion of new land into agriculture. Conventional agriculture with intensive tillage as a means of weed control and seedbed preparation is leading to further soil degradation, depletion of organic matter and nutrients, and an increase in environmental risks including the sedimentation of river systems (13). With mainly manual hoeing, for example, soil loss was 36 t/ha in a peanut/maize rotation under young rubber and 174 t/ha under rubber alone within the first year on a cleared Ultisol in Malaysia (16). Clearly, weed-control decisions and soil degradation are inseparable. These constraints must be considered together with the socio-economic factors, which have a strong influence on the final decisions of the farmers. As such, only an integrated analysis of the entire farming system can generate effective and acceptable solutions to the weed problems of farmers.

Table 3. Inputs of weed control in farming systems in developing countries

Country	Farming system	Crops	Weeding (man-day/ha)	Proportion[a] (%)	Reference
Indonesia	Shifting cultivation (new)	Upland rice	38	28	11
	Shifting cultivation (old)	Upland rice	39	24	11
	Cereal-based	Upland rice	64	46	11
	Cereal-based	Upland rice and maize	65	35	14
	Cereal-based/mulch rotation	Upland rice and maize	26	25	14
	Agroforestry (rubber)	Rice/maize/cassava/peanut	75	25	15
Philippines	Shifting cultivation	Upland rice	32	29	10
	Shifting cultivation	Tomato	60	47	10
Laos	Shifting cultivation (new)	Upland rice	198	54	9
	Shifting cultivation (old)	Upland rice	144	57	9
Malaysia	Shifting cultivation	Upland rice	35	17	20

[a] Weeding as a proportion of total labour used per cropping season.

INTEGRATED MODEL OF WEED MANAGEMENT

Classical (box) model of weed control. Classical weed control grew out of a technological need to ease labour inputs, reduce production costs and improve crop yields (17). The focus on weed technologies concentrates efforts usually on the weeds, crop and climate (Fig. 1a). In view of the strong link between weed-control decisions and soil degradation, the classical box model requires a revision.

Integrated (umbrella) model of weed management. In addition to the weeds, crop and climate, a farming system in practice consists of at least five additional major interrelated components, namely the soil, pests, diseases, farmer and, increasingly, the public at large (Fig. 1b). Consequently, it seems appropriate to adopt a "systems" approach in managing weeds (1, 5, 17, 23, 25). The umbrella model is more than just a multi-disciplinary approach. It requires weed specialists to have a broad understanding of the farming system in practical conditions in order to identify and incorporate the common needs of the farmers and the major public users (technical advisors, regulatory authorities, weed specialists, consumers and environmentalists) in the programme. Implementing this early in the planning phase of the research or extension activities ensures that the results are more relevant to the farmers and acceptable to the other user groups.

Adopting a "systems" approach does not imply the rejection of component research, which will continue to be necessary with potential applications across many agricultural systems and may encourage even better adoption of new technology by farmers. This is especially relevant in developing countries where the discrepancy is wide between new technologies and the socio-economic environment of the farming system (8).

Systems tools. Resolving weed problems from an integrated standpoint requires a new set of management tools. Some of these such as logical framework analysis, systems analysis, soft systems methodology, operation inquiry and action inquiry have been highlighted (5, 19, 23, 25). In Ciba, we are employing logical framework analysis to adapt weed management solutions in small-scale maize farms; both the farmers and extension officers are involved in this type of participatory research.

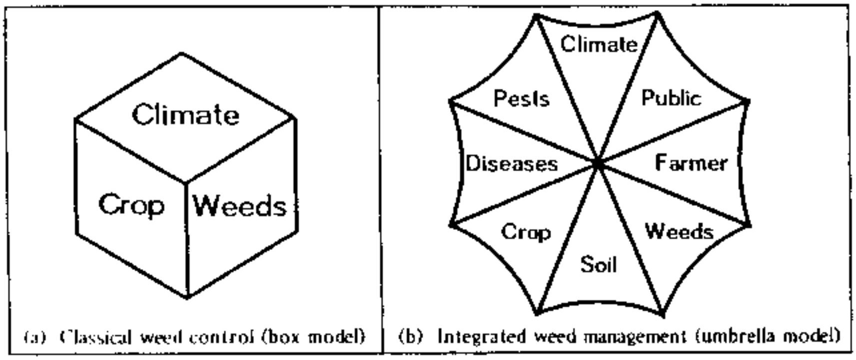

Figure 1. Classical box model of weed control (1a) as compared to integrated umbrella model of weed management in a farming system (1b). There may be more components that are just as important in other situations.

FRAMEWORK FOR WEED MANAGEMENT

Purpose of a framework. The integrated (umbrella) model is the basis for developing a framework for weed management and, subsequently, practical methods for the farmers. The framework is a generic structure consisting of a hierarchy of guidelines: the broad goal, specific objective, strategic approaches, proposed actions, expected outputs and possible applications. It is a practical "systems" tool for planning and developing weed management that fits farming systems at the farm, area, country or regional level. It is also sufficiently flexible to allow integration with other tools in weed management. As an example (Table 4), the framework is used here to develop broad concepts of weed management suitable for the developing countries, and comPare these concePts with those of conventional weed control.

Designing a framework for both weed management and weed control first requires a differentiation of weed management from weed control. The Merriam-Webster dictionary defines control as regulation, domination or rule; and management as the judicious use of means to accomplish an end. Applying these words to weeds, weed control necessitates direct intervening but usually exterminating actions, while weed management requires a combination of methods.

Weed management versus weed control. The fundamental difference between weed control and weed management lies within the pursuing goals and objectives of the farmers (Table 4). The goal of weed control is short-term and tends to maximize crop yield; the objective is to remove all weeds, if possible, from competing with the crop. However, weed management is longer-term and aims to optimize farm productivity, with the objective of maintaining weeds below levels not competing significantly with the crop, while maintaining a balance between economic, social and environmental considerations (12). Differing approaches and actions are derived from the goals and objectives, although they may share common tools such as implements and herbicides (Table 4). The outputs from weed control usually are near-perfect elimination of weeds with a high crop yield, while weed management substantially reduces weed infestations with optimum farm profits. In practice, the difference between weed control and weed management is not as clear-cut as described in the framework due to overlapping actions (practices) and similar outputs.

Table 4. Framework and concepts of weed control and weed management

Structure	Weed control	Weed management
Goal	Maximize short-term crop yield and profits	Optimize long-term farm productivity based on economic, social and environmental responsibilities
Objective	Remove all weeds, if possible, from competition with the crop	Maintain weeds at levels below significant competition with the crop
Approach	Use one to two easiest, most effective method suited to the crop	Balance the best available methods suited to the farming system
Actions	Employ full tillage technology Apply full rates of herbicides	Employ minimum tillage technology Adapt low rates of herbicides Integrate agronomic practices to increase competitive ability of the crop
Outputs	Usually near-perfect weed elimination Usually high crop yield	Usually substantial reduction of weed pressure Usually optimum farm profits
Application	Wide geographical regions	Need adaptations to specific locations/areas

In developing countries, the survival of the majority of farmers is on a day-to-day basis. As a consequence, decisions on combating weeds are based primarily on the framework for weed control. Tillage is intensive and, as a result, soil fertility declines due to extensive erosion. Weed specialists in these countries have the task of educating and training these farmers to change and adopt the broad concepts within the framework of weed management. Despite such a daunting task, there is optimism that changes in social and environmental values and perceptions will stimulate the development of weed management in line with the framework presented.

In our adapted weed management project in Ciba, we have developed for maize a weed management framework very similar to that in Table 4. In this framework, the rates of herbicides were reduced by half to manage weeds to below 20% of soil cover; this was made possible with one supplementary manual weeding with a hoe. Early results indicate that reduced rates of herbicides, together with one manual hoeing, for weed management could be possible options for small-scale maize farmers; the full agronomic and economic data are being collected and studied (Ciba, unpublished data).

DEVELOPING WEED MANAGEMENT FOR TOMORROW

Basic principles. There are no ready-made broad-based solutions in weed management because it is more location-specific than weed control. It requires a concerted effort from all parties in the planning and implementation of weed research and extension services for the farmers. The integrated model and framework for weed management presented can guide weed specialists to select a combination of methods best suited for the specific situation.

The intervening methods can be physical, chemical, biological or ecological (1), and are directed towards the weeds, crop and soil within a set of climatic and soil conditions (Fig. 2). These methods aim to exploit the weaknesses of the weeds and promote the growth and competitiveness of the crop in order to reduce weed infestations to levels which are not competing significantly with the crop. The alley-cropping system for example, is an illustration of weed management. Cut materials from the alley crops were applied on the soil surface to suppress weeds in maize for 30 days; a light hoeing or low rate of a herbicide kept weeds below 20% of the soil cover for another 30 days, after which weed control was not needed (12).

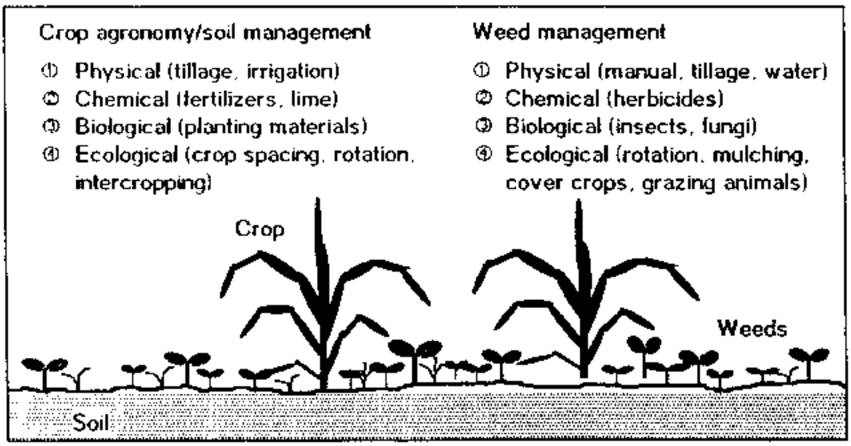

Figure 2. Possible wide ranging intervening methods for weed management.

<u>Technology</u>. When considering weed management for tomorrow, it remains an essential tool to raise agricultural productivity in developing countries. Weed management must conform to the needs of farmers, which means being simple (easy to use), effective (reduces weeds and increases crop yield), efficient (involves less effort and time), robust (produces consistent results over time), flexible (adaptable to the entire farm) and motivating (feels good to use it without risk). The needs of farmers, however, may sometimes be contradictory to environmental considerations. For instance, the alley-cropping system is one of the most environmentally - friendly agricultural technology, but cutting the alley trees is hard work in addition to the loss of alley-crop space to the target crop; adoption is low as a result (8). Improving alley-cropping system or even adapting low rates of a herbicide to satisfy the various user groups focuses on opportunities to improve weed management through innovation.

Continuous research into herbicide technology also results into discovery of new molecules that are more appropriate as well as adaptations of existing active ingredients to provide safer products. As an example, the recent introduction of the low-rate mixture of cinosulfuron (sulfonylurea) and pretilachlor (chloroacetamide) in water-soluble bag by Ciba for use in rice in Thailand is a positive trend towards safer herbicide technology.

CONCLUSIONS

In developing countries in the Asia-Pacific region, the widening gap between agricultural technology and society requires weed specialists to adopt innovative approaches in weed management. Central to this is the need to maintain the balance between economic, social and environmental concerns. This requires an analysis of the entire farming system and its interrelated components. Weed specialists can develop a framework for weed management using a variety of practices that will satisfy both the requirements of the farmers and the public. The available weed technologies are wide and, generally, require some modifications to fit the new approaches. In addition to this, there is a need to design the new technologies, such as minimum tillage, alley cropping and low-rate herbicides, based on the prevailing economic, social and environmental concerns.

Unlike what is happening to developed nations, developing countries in the Asia-Pacific region have relatively more time to tackle the emerging public values and perceptions. Already, the balancing of economic, social and environmental responsibilities is guiding the activities of various organizations like Ciba and the International Rice Research Institute (IRRI). In other words, achieving short-term profits or benefits is of lower priority than maintaining a forward - thinking, long-term approach. As weed specialists, we have been asked the relevant questions, and the answers are in our hands. It is up to us to take up this new challenge of the 21st century and contribute to the betterment of the farmers and society in our region.

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THE CONTRIBUTION OF PLANT BIOLOGY AND ECOLOGY TO THE BIOLOGICAL CONTROL OF WEEDS

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Summary. Biological control is often thought of as applied entomology or applied plant pathology. However, in many cases, different plant science disciplines can contribute to the success of biological control; either directly, by aiding the choice and establishment of agents and promoting their effectiveness, indirectly, by showing us reasons for the failure of certain introductions and thus adding to the scientific base of biological control, or in a complementary role through the incorporation of biological control into overall weed management strategies. In this paper, examples are given where studies on plant ecology, population genetics, taxonomy, physiology and agronomy have significantly aided the control projects concerned or can contribute to future work. Biological control of weeds is a multidisciplinary science and, too often, biological control workers have had to undertake studies in areas outside their own discipline, leading to loss of time and/or effectiveness. Closer co-operation between "plant specialists" and "control agent specialists", both in the lead-up phase to control projects and in the integration of biological agents with cultural and chemical control methods, should increase the efficiency and success rate of biological control against target weeds.

INTRODUCTION

Biological control of weeds is a management practice based on the hypothesis that natural enemies can regulate the density of their host species. The definition of biological control (see (28)) as the "study and utilisation of parasites, predators and pathogens to regulate populations of pests" underlines the historical emphasis of biological control on the role of the control agent rather than the target weed. In fact the key researchers in most weed biocontrol programs are usually insect ecologists or plant pathologists. An examination of the papers presented at international symposia (Fig. 1) shows this, but also indicate that in recent years a small but increasing number of papers are appearing which deal with aspects of the biology of the target weed.

Despite the perception of biological control by many as either applied entomology or applied plant pathology, it is a practice that draws on a wide range of scientific disciplines. As shown in Fig. 1, it has flourished in recent years, fuelled by the spectacular successes of some programs (e.g. *Chondrilla juncea* in Australia and most recently, *Salvinia molesta* in New Guinea, Southeast Asia and southern Africa). However, such successes are not the norm, for in many programs individual introductions of natural enemies may fail completely (33), with a large proportion of programs only achieving partial success or succeeding only after a long and arduous study. Biological control practitioners realise that in order to improve the efficiency of programs it is essential to have a better understanding of plant-herbivore interactions and the processes involved when the population dynamics of a plant are modified by the introduction of natural enemies. It is in these latter cases that specific studies of the biology and ecology of the target weeds currently make their most visible contribution to their biological control; by aiding evaluation of the level of control achieved, identifying problems that have impeded greater agent impact and showing how these can be overcome or avoided. However, plant-oriented studies can also help improve efficiency at all levels of the biological control program, from agent selection to the integration of biological control into an overall weed management strategy.

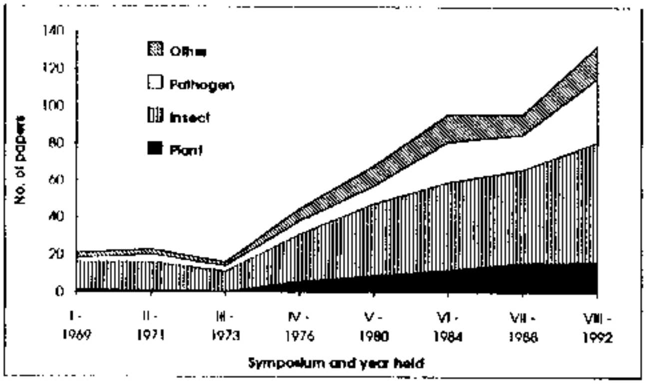

Figure 1. Breakdown of papers, by principal subject matter, presented at the International Symposia for the Biological Control of Weeds.

Without attempting to be an exhaustive review, this paper illustrates how different plant science disciplines have aided biological control programs throughout the various phases of their operation, and suggests area in which a greater input from plant scientists is likely to be beneficial.

FINDING THE RIGHT AGENTS AND ASSESSING THEIR POTENTIAL IMPACT

One of the most critical phases of any weed biological control program is the selection of appropriate agents. The need for strict host specificity certainly reduces the pool of available candidates, but if the program is to be more than just a "collect and release" effort, some further culling and setting of priorities is essential. This is best done following a detailed study of the biology of the target weed, in order to discover aspects of its life cycle that either may be exploited by certain agents or may diminish the impact of others. For example, seed predators may not be the best agent for a weed that reproduces mainly by vegetative means. Sheppard et al. (50) looked at the population dynamics of *Carduus* spp. in their native Mediterranean range and were able to show that, while pre-dispersal seed predators could have an impact on the biennial, *C. nutans*, they were relatively ineffective against the shorter-lived annual, *C. pycnocephalus*. In the latter case, fungal pathogens appeared more likely to be useful control agents as they could respond more quickly to the plant's shorter life cycle.

A powerful means of determining the potential impact of control agents is to undertake comparative studies of the population dynamics of the weed both in its introduced and native ranges, and of the factors that drive them. Such studies on thistles of the genera *Carduus* (51, 58) and *Onopordum* (7, 11) showed that soil seed banks in Australia were substantially larger than those in their European native range. This was found to be largely due to heavy pre-dispersal seed destruction in Europe and suggested that priority should be given to introducing those control agents able to reduce the seed rain and hence the soil seed bank.

Unfortunately, this type of study is often only carried out following lack of success of the control program. The Australian program against *Hypericum perforatum* was only a partial success. The defoliating beetles, *Chrysolina* spp., introduced in the 1930's, were successful in certain situations (see section on Integrating Control Measures later), but unable to control the weed in others (4, 17). Detailed studies by Clark (18) on the population dynamics of the target weed showed that certain soil types favoured vegetative reproduction and the maintenance of strong sub-soil reserves enabled the plant to recover from defoliation, particularly under summer rainfall regimes (30). These studies showed that, for biological control to be more successful, agents were needed that could weaken the root reserves of *H. perforatum*, and have led to the recent introductions of a root-borer, an aphid and a cell-sucking mite. While too early to claim success, they offer an improved chance of finally managing this problem weed.

It is at the agent choice stage that plant taxonomy can make an important contribution to biological control. Quite often, the level of specificity is such that agents may be more effective against one form of weed than another. Examples of this are known from arthropod control agents, e.g. *Aceria chondrillae* on skeleton weed, *Chondrilla juncea* (41), and the insects introduced against *Lantana camara* (45), but the level of specificity is particularly relevant for fungal control agents e.g. *Puccinia chondrillina* against *C. juncea* (22), *Phragmidium* against members of the *Rubus* complex (8). Clarification of the taxonomic status of host weed forms has significantly helped in the search for agent biotypes effective against particular forms of the target weed in the cases of *Rubus* (1), *Lantana* (see 54, 55), *C. juncea* (13, 31) and *Carduus* (45). The techniques involved range from classical morphological taxonomy (1, 31, 55) through chromosome studies (54) to protein electrophoresis (13) and chemotaxonomy based on secondary plant compounds as in the case of *Euphorbia* (35). In the latter case this technique is helping to unravel the European species complex and facilitate the search for fungal agents of those *Euphorbia* taxa that have invaded North America (29).

In the case of *C. juncea*, Chaboudez and co-workers (13, 15) have extended the use of electrophoresis to undertake a study of the population genetics of the target weed in its native range. This permitted them to identify the centre of evolution of the plant in western Turkey, and to focus the search area for strains of the rust fungus effective against certain Australian and American forms of skeleton weed. The extended use of modern diagnostic techniques characterising biotypes is one area where plant science may make an increasingly important contribution to biological control.

EVALUATING THE ACTUAL IMPACT OF AGENTS

Once selected, host-tested and released into a new habitat, there are three possible outcomes for a biological control agent: it may succeed spectacularly and give total control of the weed, such as happened with *Opuntia*, *Hypericum* in California, the narrow-leafed form of *C. juncea* and *Salvinia*; it may fail completely, as has happened in 76% of the agent releases to date, or it may have a partial effect on weed infestations (18% of cases) (data from 34) . This latter category covers a range of possible outcomes, and adequate evaluation becomes a critical element, for the biocontrol practitioner needs to know what level of impact he has made on the target weed, what options he has to improve this and whether (and how) other control agents might contribute to the level of success.

Such information can only be obtained by looking at the population dynamics of the target weed as affected by the control agent. These studies can consist either of monitoring natural field populations and interpreting the observed patterns in weed population and/or setting up critical experiments designed to answer specific questions. Unfortunately, it is rare to find such quantitative evaluation studies in the literature (36), even though simple experiments may give valuable insights into the functioning of the system. For example, Myers *et al.* (44) were able to show, from plant removal experiments, the potential of *Centaurea diffusa* to compensate for insect attack through density-dependent survival and growth of different plant stages.

Combined studies of the population dynamics of target and agent are undoubtedly the most instructive. Where the time and effort has been invested in this type of evaluation, such as in the *Senecio* control program in North America, a detailed understanding of the failure or success of particular agents has been obtained. Studies of the ragwort-cinnabar moth system over 4-6 years at 9 sites demonstrated that weed population dynamics were largely being driven by environmental factors, and in turn controlled the dynamics of the natural enemy, rather than the reverse (43). Subsequently, McEvoy and co-workers (32, 37, 38) combined the use of long-term monitoring of plant demography, coupled with specific experiments on artificially created weed populations to demonstrate the effectiveness of a second agent, the flea-beetle *Lonitarsus jacobeae*, in the control of *S. jacobeae* in north-western USA. Plantdemography data collected by them from 42 sites over periods up to 12 years clearly showed a decline in the weed and its replacement by preferred pasture species, while establishing that the persistence of a large seed bank poses a continuing threat to restructure of the target weed affected agent impact, as well as demonstrating the importance of competition by other pasture plants. An important finding was that the overall dynamics of the ragwort populations seemed to have changed from that of large self-perpetuating infestations to a metapopulation structure with frequent extenctions and establishments, rather than to a stable low-density equilibrium in the presence of its natural enemies.

The importance of a target weed's population structure to the dynamics and subsequent impact of its herbivores has been stressed by Briese (5) for the *Hypericum-Chrysolina-Agrilus* system. In this case, if detailed plant demographic data had been collected for the weed in its host range it may have led to a different strategy for agent introduction and a more stable equilibrium in the population of the weed in its introduced range in south-eastern Australia.

One way of better predicting the potential impact of agents is to model weed populations dynamics. The program to control *Centaurea* spp. in North America has not yet shown the level of success anticipated, despite levels of seed destruction up to 94% by introduced insects (19). A model of density-dependent birth and death rates for *C. diffusa* (46) confirmed the resilience of this species to damage by introduced natural enemies, while simulations of Centaurea population dynamics using Leslie matrix models (19) indicated that seed output needed to be reduced by 99.5% before plant density would be affected. The model predicted that, at present seed loss levels of 94%, control could also be achieved by an agent that removed 90% of seedlings. While these values cannot be verified, the models support the present strategy of introducing insects which directly attack *Centaurea* rosettes.

Plants that reproduce vegetatively are also amenable to this type of approach and the modelling exercise can be approached from a spatial as well as a strictly numeric viewpoint. Such a model was developed by Room (47) to look at the architecture of vegetative growth in *Salvinia*, and could be used to make predictions of the Hypericum-Chrysolina-Agrilus system. In this case, if detailed plant demographic data had been collected for the weed in its host range it may have led to a different strategy for agent introduction and a more stable equilibrium in the population of the weed in its introduced range in south-eastern Australia.

Studies on plant physiology have also helped to evaluate agent impact, though such studies are facultative and usually only arise when there is a particular need for this type of information. For instance, gall-forming flies are considered important agents in the control of several thistle species. Detailed morphological study of gall formation in *Centaurea* thistle heads by *Urophora* spp. was able to show how these insects control the growth of plant tissues forming physiological sinks which rechannel nutrients from other plant parts (52). In fact, it could be demonstrated from the thickness of the nutritive cells in the gall that *U. affinis* was more effective in this regard than *U. quadrifasciata*. Similarly, to better understand the observed relationship between plant quality in water hyacinth *Eichhornia crassipes*, and the effectiveness of its agent, *Neochetina eichhorniae*, Center & Wright (12) examined the phytochemical composition of leaf tissue with respect to age. Such an approach has also confirmed that the impact of sub-lethal doses of the herbicide, 2,4-D, on leaf nutrient levels and hardness of this species can favour feeding by the control agents (59), and opens up the possibility of integrating control measures. Studies on the way individual plants of different species compensate for herbivore defoliation (54) can also help understand natural enemy impact.

Undoubtedly, though, the most spectacular example of physiological studies aiding biological control stems from the *Salvinia* program. Detailed studies carried out on nutrient requirements of this aquatic weed showed the key role of nitrogen in driving its population dynamics (49). When initial releases of the control agent, *Cyrtobagous salviniae*, failed to establish in New Guinea, this knowledge, coupled with that of nutritional requirements of the agent, suggested that raising nitrate levels in the plant at the release sites might improve establishment. The fact that weekly applications of urea fertiliser triggered off a self-sustaining population explosion of the agent and subsequent widespread control of the weed, turned potential failure into the most successful recent control program (48).

INTEGRATING CONTROL MEASURES

Once the demography of a weed starts to be modified by natural enemies, other components of the plant community in which it occurs are perturbed e.g. the synergistic effects observed between competition from clover and the *Puccinia* rust fungus on *Chondrilla juncea* in pastures (22) or the similar interactions between soil nutrient levels, competition from pasture grasses and natural enemies described above for *Senecio* (38) and *Centaurea* (42). The situations in which biological control was successful against St John's wort in south-eastern Australia were those where improved pastures could replace the weed following initial agent perturbation of the system (25). The challenge for biological control is to find ways of integrating this technique with other management options in order to produce an overall management strategy for particular situations.

Trumble and Kok (56) have described such a strategy for the control of *Carduus* nutans in North America, involving pasture and grazing management, chemical and biological control. They have demonstrated that biological control can be compatible with these other methods, even with herbicide use, provided timing of application is considered (56). Integration of biological control with other methods is a real option for thistle-infested pastures in Australia (53), as complementary studies have already been made on the effects of competition by pasture species (39, 40) and grazing management (2, 24) on thistle densities. The pasture agronomist is likely to play the key co-ordinating role in integrating these different methods into a viable management strategy (26).

While fewer alternative options are available for environmental weeds, biological control can possibly be integrated with existing management tools. Controlled burning is used in conservation areas in south-eastern Australia to reduce fuel and prevent large wild fires. *H. perforatum* is a weed that invades native forest, and responds to low intensity fire through rapid regrowth from surviving rootstocks. This is largely due to elimination of competing species and a fertiliser effect from the ash. However, evidence suggests that, provided natural enemies survive in refugia near the burnt area, they respond to the increased nutrient levels in the regenerated plants, similarly to the case of *Salvinia* mentioned earlier, and thereby inflict higher levels of damage on these than normal (6). Thus, burning in a mosaic pattern to provide both refugia and areas of nutrient enriched host weed should provide more effective long-term control.

CONTRIBUTION TO BIOLOGICAL CONTROL THEORY

There is no "Theory of Biological Weed Control" as such, but there is a strong move to try and identify the common factors between different projects to determine whether certain properties of weed species make them more amenable to control or to identify those agent properties that make them good control agents (20, 21). This is driven by the need to improve the rate of success of weed biological control projects (33). While it is true that each weed project in a particular region needs to be treated individually, the more that is known about the set of interactions triggered by agent introductions the more predictable the outcome. Thus, all input from plant science disciplines is contributing to the theoretical framework of weed biological control as well as to its application.

In certain cases this framework can be challenged more directly. A good example of this is the hypothesis put forward by Burdon and Marshall (9) that the genetic structure of plants will determine the susceptibility of that plant to biological control; outbreeding plants being genetically more variable and thus more likely to have forms resistant to agent impact or amenable to selection for such resistance. This idea proved very controversial, and generally is considered to have limited application to systems where there is a very tight agent-plant association, such as with plant pathogens. However, it served a useful purpose in generating debate and obliging research workers to consider to what extent particular life-history traits and biological properties might make certain plants better candidates for biological control than others (14, 20).

CONCLUSIONS

The examples given above are sufficient to demonstrate that, for biological control to become a more effective and more predictable method of managing weed infestations, there is a need for a significant input from the plant science disciplines (Fig. 2). With some notable exceptions, most programs to date have been "agent-centred". What is needed is to rephrase the basic research question from "what type and how much damage can agent A do to weed B?" to "what will happen to the population dynamics of weed B if we introduce agent A into its life-system?". This refocusses attention on the weed rather than the agents and emphasises the need for ecological studies of the weed in its native range where the agent is already a component of the system, as well as the more common "before and after" studies in the region of introduction of the natural enemies. Such studies are particularly valuable for complex terrestrial weed systems as they can demonstrate the interaction between natural enemies and other factors, such as plant competition and environmental effects. It is no coincidence that *S. jacobeae* is the weed that has been most studied in its native range (38) and also the weed for which the reasons for success of biological control (or lack thereof) are best understood.

Apart from classic life-table type studies, some areas of plant ecology will have an increasing input into the biological control of weeds. As indicated above the nature of the end-point population dynamics (both spatial and temporal) of the target weed can determine the sustainability of control. One important aspect of this is seed bank dynamics, as most weed infestations are characterised by very large soil seed banks which remain shielded from natural enemy attack. The importance of these to the end point attained in a control program is critical, yet very few studies have accurately quantified them (3), let alone the interactions between seed availability and microsites that determine the establishment of weed infestations (27, 51).

Modelling these systems should also be more widely used as a tool to predict and evaluate the impact of control agents, and should expand to include temporal-spatial as well as quantitative information about weed population dynamics. These models may not only include the impact of natural enemies, but could be expanded to consider other components of the weed's life-system, such as competition from other plants, eventually being incorporated into models of pasture or crop management strategies. Campbell (10) has pointed out that, in practice, there has been little active integration of weed control techniques. If genuine integrated weed control is to be achieved, modelling must play an important role.

In view of the aim of biological control to "restore" the balance between plant and natural enemies, the key to effective biocontrol is to understand the population dynamics of the target weed, supported by facultative inputs from physiological, taxonomic or population genetic studies to understand particular aspects of host-plant interactions (Fig. 2). In the majority of cases mentioned here, the studies have been undertaken by the key researcher(s) working outside their area of specialisation. This does not mean that the work is in any way inferior, but it does waste resources and time (the latter being a critical factor as far as funding bodies are concerned), and co-operation between specialists in different aspects of weed management is more likely to have a synergistic effect (26, 28).

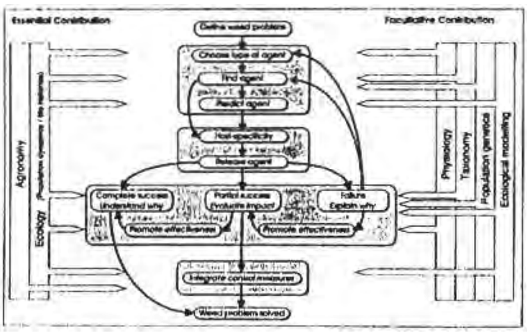

Figure 2. Phases of a biological control program showing areas where contributions from plant science disciplines can be important (italics indicate phases not always carried out at present).

The ultimate future for biological control of weeds lies as one component of integrated pasture, cropping or natural area management systems. Without downgrading the importance of understanding the biology of the agents themselves, this necessitates a more phytocentric approach (*sensu* Dirzo (23)) involving multidisciplinary teams, where the control agent is viewed as one component of the weed's life system. The resultant increased input from other plant science disciplines should lead to greater efficiency in the practice of biological control and to greater use being made of its potential.

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THE AUSTRALIAN NATIONAL WEEDS STRATEGY

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Summary. The National Weeds Strategy document outlines the extent, the economic and ecological impact, and potential of weed problems in Australia. It discusses the main issues of weeds, which confront governments, landholders, weed scientists and the general public today. It proposes five main recommendations to improve the effort in weed management in Australia: i) review of Commonwealth quarantine legislation (import of plants); ii) review of State and Territory legislation relating to noxious weeds, sale and transport of weeds and weed-contaminated produce; iii) education support and community involvement re the economic, social and ecological impact of weeds; iv) a catchment management approach to weed management. A policy and operations structure is proposed which includes (v) the appointment of a National Weed Management Coordinator to help implement the Strategy with advice from a weeds research and development working group to prioritise R and D effort.

INTRODUCTION

A National Weed Strategy document was prepared in response to community, landholder and government concern that a better way was needed to manage weeds in Australia. A taskforce under the auspices of the Standing Committee on Agriculture was set up within the Australian Weeds Committee framework to prepare a draft document for public comment.

The taskforce considered 98 initial submissions and Dr L Smith met with State Government departments and others interested in weeds before a draft document "Towards a National Weeds Strategy" was released for public comment in October 1992. There were 570 requests for the draft which elicited almost 100 written responses for consideration. The majority (80%) were responses from government, local government, companies and community groups such as Landcare and wildlife societies.

The strategy documents the impact of weeds on all sectors of Australian society. Weeds occur in rangelands, cropping and pasture land, aquatic and semi-aquatic systems, conservation areas, plantation forestry and urban and industrial sites with varying effects. Many weeds have not reached their ecological limit. Weeds reduce yields of crops and pastures, lower value of plant and animal products, affect human and animal health, contaminate water supplies, act as hosts for insects and diseases, cause fire hazards, alter the structure, composition and function of natural ecosystems and interfere with sustainable land use practices. They can be a major influence on land degradation to the detriment of native flora and fauna (3).

It is estimated that weeds cost Australia over $3,000 million annually (1) yet only land managers or policy analysts with direct experience of these problems appreciate their full impact.

There are many exotic species known to be weeds which are not recorded in Australia and every effort must be made to prevent their entry. Of the 17,000 plant species occurring in Australia, 11% are introduced and about half of these (approximately 900-1000 species can act as weeds). New plant species are being introduced at 4 to 6 species per year. Of the 220 introductions proclaimed noxious, 46% were brought in when there was less appreciation of the latent ability of plants to express a disproportionate vigour in another environment. The Strategy recognises that undesirable plant growth, in the form of weed infestations, has adversely affected our quality of life and economic and ecologically sustainable weed management systems must be developed and implemented for our well being.

CURRENT ISSUES

Role of Government

Philosophy. The role of government in natural resource management is to define, assign, promote land stewardship and enforce rights of ownership and use of resources in the interest of society as a whole. This has not been done effectively with weeds at all levels of government and is one of the main reasons why a National Weeds Strategy is required. The principle to be followed in assigning action is that of Ecologically Sustainable Development.

For sheer geographic scale weed issues in the arid and semi-arid rangelands qualify as the most serious and intractable problems (3). In these areas some weeds such as *Acacia nilotica* (prickly acacia) in western Queensland are symptoms of unsustainable grazing pressure and a remedy will require attention to social as well as weed control issues.

Legislation. The *Quarantine Act, 1908* regulates the import of plants into Australia and although the Australian Quarantine and Inspection Service (AQIS) carries out its duties diligently, plants are sometimes imported which become weeds. This was highlighted when *Kochia scoparia* was introduced into Western Australia for revegetation of salt affected land. A risk assessment system is needed which evaluates proposed plant introductions as to their potential to become invasive in both agricultural and conservation areas. The *Wildlife Protection (Regulation of Exports and Imports) Act, 1982* also regulates entry of plants into Australia and there is a need to rationalise the import control and quarantine functions of both Acts so that the risk of potential weeds entering Australia is minimised.

At State level there are numerous pieces of legislation which deal with weeds, but there are anomalies or a lack of consistency in areas of sale and transport of weeds and weed-contaminated produce, especially noxious weeds. In some cases there is a lack of legislation altogether.

Community involvement. The community can be a powerful force for managing weeds in local areas, but the problem is how best to harness and maintain their enthusiasm. It is necessary to engender a sense of stewardship of the land and its problems in the community. Expansion of Landcare programs to cover all weeds issues is necessary.

The use of a regional or catchment management approach to weed control enables the community and government to achieve a more balanced and coordinated effort in weed management. Control of weeds can be integrated with control of feral animals and with soil conservation strategies.

Sanctions in the form of penalties are already in place under State/Territory legislation but are not always enforced, usually for valid reasons. Incentives and sanctions will be more effective if the community is aware of the social, economic and ecological implications of not controlling or not preventing the spread of weeds.

Research and development. No formal mechanism exists for setting national research priorities and while some States and industry bodies do set priorities the methods used are not consistent and involve little community consultation. Blacklow (2) concluded in 1984 that weeds research in Australia was essentially carried out by part-time researchers with insecure funding.

The present level of research in the taxonomy, biology and ecology of weeds is considered to be inadequate, yet these disciplines are fundamental to the development of integrated weed management systems. Quantitative data of the economic and ecological impact of weeds, especially on biodiversity, needs attention for priority setting purposes. Pooling and sharing of resources should be promoted and Cooperative Research Centres developed for weeds as with other disciplines.

Herbicide strategies should be aimed at increasing efficiency of herbicide use, increasing environmental and human safety and creating an awareness in the community that herbicides are an essential component of good vegetation management. Specific areas of concern are i) over-use and persistence in soil and water (surface and groundwater), ii) herbicide resistance, iii) registration for minor crop use, and iv) over regulation of use.

Education and training. There is concern about the run down in weed science training at university level and the lack of opportunity for post graduate training of weed specialists. Training of weed control operators and practitioners is essential and there is a need for a TAFE level training course which will license these people at a uniform standard.

RECOMMENDATIONS

1. Structure. Any strategy is required to document a process for analysis of the problem, priorities for action, management, feed-back and response to project outcomes. The NWS recommends problem analysis and priority setting through a series of workshops and conferences to be organised by the National Coordinator, assisted by State and Territory Department representatives. The recommendation is for the Coordinator to be appointed within the Bureau of Resource Sciences to drive development of an operating plan, the development of more stringent plant introduction legislation, a model action plan for weed outbreaks and act as convenor of the working groups. An initial term of three years is proposed.

For effective recommendation on research and development, the Strategy proposes a segmentation into ecosystem or land-use categories each with a specialist working group appointed to be responsible for recommendations for action. The categories proposed are:

- tropical and subtropical crops, pastures and plantations,
- temperate crops, pastures and plantations,
- aquatic habitats and ecosystems,
- tropical and subtropical native forests, rangelands and nature conservation areas, and
- temperate native forests rangelands and nature conservation areas.

Initiatives in research should include prediction and prevention of spread; integrated weed management with a view to reducing reliance on herbicides; research policies for herbicide resistant cultivars of crop and pasture species; monitoring herbicide residues in soil, water and the environment; development of weed management policies based on ecological and economic principles; and revegetation and rehabilitation of ecosystems.

The Strategy does not specify the priorities for research or implementation of current knowledge against particular weed problems. It is expected that this detail will occur as a result of group consultation.

2. Legislative action. Since weeds to a large extent are a legacy of deliberate plant introductions which possessed unsuspected abilities for invasiveness in alternative environments, more rigorous screening procedures are an obvious first step in a Strategy.

Review of Quarantine Legislation. Evaluation of plant introductions requires a risk analysis assessment method based on their potential to become invasive in both agricultural and conservation areas. The *Quarantine Act,* 1908 and complimentary legislation must be reviewed to ensure a more stringent plant introduction procedure, with denial of automatic entry for plants that may pose a risk and with the cost of risk analysis assessment borne by the importer.

Review of State/Territory Legislation. A working party is recommended to review existing Commonwealth, State and Territory legislation on weeds with a view to eliminating anomalies and implementing more uniform systems. Legislation should bind governments to control noxious weeds on public lands.

3. Public Awareness and Education. Weed management must be promoted as part of ecologically sustainable development (ESD) with increased public awareness, educational support and community involvement to ensure that the economic, ecological and social impacts of weeds are recognised. Specific awareness and education programs to focus on the benefits of preventing entry of new weeds to Australia, weed seed hygiene, the significance of weeds in relation to land degradation, and to address public concern about use of herbicides are required.

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WEED DISTRIBUTION AND INFESTATION IN CHINA

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Summary. The distribution and infestation of weeds in Chin! de0end on temperature, water (rainfall or irrigation), soil, light duration and cropping system in various location at different latitudes, longitudes and altitudes. There are some representative weeds in different zone.

A. Tropic zone: *Dactyloctenium aegypiacum, Hedyotis costata.*
B. South subtropics zone: *Ageratum conyzoides, Paspalum conjugatum, Alopecurus aequalis.*
C. Subtropic zone: *Leptchloa chinensis, Alternanthera philoxeroides, Alopecurus aequalis.*
D. Warm temperate zone: *Descurania sorphia, Acalypha australist, Amaranthus retroflexus.*
E. Temperate zone: *Avena fatua, Polygonum convolvulus.*
F. North temperate zone: *Galeopsis bifid, Avena fatua.*

There are 53 million hectare of weed infestation areas in China. The total grain yield loss caused by weed infestation was estimated at 15 billion kg per year.

INTRODUCTION

Surveying method of 7-degree damage by weeds according to weed coverage was developed by R.J. Froud-Williran and R.J. Chancellor in 1982 for investigating weed infestation in wheat fields in south England (1). The surveying method of 5-scale weed infestation in crop field in China according to relative coverage, height and density of weeds was established by the author in the study carried out in 1981-1992, more than 30 thousand field plots had been surveyed in 300 counties belonging to 28 provinces or cities, for investigating the composition, distribution and infestation of field weeds in China according to different latitudes, longitudes, altitudes, soil and cropping system. The results of research work on wee$ distribution and infestation in China may serve as a basis for the practice of weed control, especially for making strategy on herbicide development and industry in China (2).

MATERIAL AND METHOD

Weed infestation degree was estimated by visualisation method according to the relative coverage of weeds (R.C. = weed coverage/crop coverage), relative height of weeds (R.H. = weed height/crop height) and relative density of weeds (R.D. = weed density/crop density). The infestation degree of weeds were classified into 5 scales as fallow:

1 degree: a few weeds are present but do not damage crop.
2 degree: light damage R.C. = 5% - 10% (R.H. = 50%-100%)
R.C. = 10% - 30% (R.H. < 50%)
3 degree: middle damage R.C.= 10% - 30% (R.H. = 50%-100%)
R.C. = 30% - 50% (R.H. < 50%)
4 degree: serious damage R.C. = 30% - 50% (R.H. = 50% - 100%)
R.C. > 50% (R.C. < 50%)
5 degree: very serious damage R.C. = 50% - 100%(R.H.= or > 50% (Table 1)

Table 1. The data for rating weed infestation level by visualisation method

Infestation level	Relative height (R.H.)	Relative coverage (R.C.)	Relative density (R.D.)
1	50%-100% <50%	5%> 5%-10%	
2	50%-100% <50%	5%-10% 10%-30%	25%-50%
3	50%-100% <50%	10%-30% 30%-50%	50%-100%
4	50%-100% <50%	30%-50% 50%-100%	
5	>50%	>50%	

RESULT AND DISCUSSION

According to the data from investigation, the distribution and infestation of field weeds in China depend on the temperature, water, soil, light duration and cropping system at different latitudes, longitudes and altitudes. There are some typical representative weeds in different areas.

The areas at latitude 18-22 N. degrees. It belonging to tropic zone where the mean annual temperature is between 22-25°C, the cropping system is rice-sugar rotation. The representative weeds are *Dactyloctenium aegyptiacum*, *Hedyotis costata*, *Eupatorium odoratum*, *Sphenochlea zeylanica*, there are no winter crop and related weeds.

The areas at latitude 23-26 N. degrees. The representative weeds are *Ageratum conyzoides*, *Jussiaea repen*, *Paspalum conjugatum* and some winter weeds *Alopecurus aequalis* and *Malachium aquaticum* in east flat and hill field belonging to south subtropic zone where the mean annual temperature is 20-21°C, the annual rainfall is more than 1000 mm, the cropping system is rice-sugar-wheat, rape or green manure rotation with three crops in a year.

The representative weeds are *Echinochloa crusgalli*, *Cyperus difformis*, *Leptchloa chinensis*, *Sagittaria pygmaea*, *Potamogeton distinctus*, *Alopecurus aequalis* and *Malachium aquaticum* in YunGui plateau areas belonging to subtropic zone where the elevation is 1000-2000 M. The mean annual temperature is 14-18°C and cropping system is rice-wheat or rape or green manure rotation with two crops a year.

The representative weeds are *Avena fatua*, *Thlaspum arvense*, *Senecio vulgaris*, *Escholtzia ciliata* and *Polygonum nepalense* in high mountain area belonging to temperate zone where the elevation is 2500 M. The mean annual temperature is between 2-7°C, the annual rainfall is 800-1000 mm. the cropping system is potato-barley or rape rotation with one crop a year.

The areas at latitude 27-34 N. degrees. The representative weeds are *Leptochloa chinensis*, *Paspalum distichum*, *Alternanthera philoxeroides*, *Digitaria sanguinalis*, *Chenopodium album*, *Cyperus difformis*, *Echinochloa crusgalli*, *Monochoria vaginalis*, *Chenopodium serotinum*, *Rotala indica*, *Sagittaria pygmaea*, *Alopecurus aequalis* and *Malachium aquaticum* in the YanZeiver basin areas belonging to the subtropic zone, from east coast to Sichuang Province, where most fields are located in low elevation, flat and hilly lands, the mean annual temperature is 14-18°C, the annual rainfall is about 1000 mm, the cropping system is rice-wheat (barley, rape) or cotton-green manure rotation with two crops a year.

The representative weeds are *Avena fatua*, *Thlaspum arvense*, *Senecio vulgaris*, *Galium aparine* and *Polygonum nepalense* in west Sichung-Tibet Plateau areas and some high mountain areas where the elevation is 2000-3000 M. The mean annual temperature is 5-7°C, it belongs to temperate zone, the cropping system is wheat or barley-potato with one crop a year.

The areas latitudes 33-40 N. degrees. From Huai river to Great Wall, the representative weeds are *Descurania sorphia*, *Eleusine indica*, *Acalypha australist*, *Chenopodium serotinum*, *C. album*, *Setaria viridis*, *Polygonum lapathifolia*, *Amaranthus retroflexus*, *Convolvulus arvense*, *Galium aparine* and *Capsella-bursa-pastoris* in HuangHe, HaiRiver and Hai river basin areas, belonging to warm temperate zone, where the mean annual temperature is 10-13°C, the annual rainfall is 500-800 mm, the cropping system is cotton-corn-soybean(peanut)-wheat rotation with three crops every two year.

The representative weeds are *Convolvulus arvense*, *Avena fatua*, *Chenopodium album*, *Setaria viridis* in Huangttu plateau areas belonging to temperate zone where the elevation is about 1000 M. The annual rainfall is below 500 mm, the cropping system is corn-sorghum-wheat (barley) rotation with one crop a year.

The representative weeds are *Avena fatua*, *Polygonum convolvulus*, *Elsholtzia ciliata*, *Galeopsis bifida* and *Lepyrodiclis holosteoides* in QiuHai plateau areas belonging to temperate, north temperate zone where the elevation is 2400-3000 M. The mean annual temperature is 5-7°C, the annual rainfall is about 500 M. The cropping system is wheat (barley)-rape-potato with one crop a year.

The representative weeds are *Avena fatua*, *Chenopodium album*, *Convolvulus arvense*, *Phramitis communise*, *Polygonum aviculare* and *Scirpus planiculmis* in some irrigation fields of desert in XinJiang, GanSu basin areas belonging to warm temperate zone and temperate zone where the mean annual temperature is about 10°C, but day is high, night is low, the annual rainfall is below 100 mm, the field crops depend on irrigation system, the cropping system is rice-cotton-wheat rotation with one or two crop a year.

The areas at latitude 40-50 N. degrees. These areas are situated outside Great-Wall, in Liaoning, JiLin and HelongJiang, where the mean annual temperature is 2-8°C, the elevation below 500 M, the annual rainfall is about 500 mm. The cropping system is wheat-soybean-corn-rice rotation with one crop a year, the representative weeds are *Avena fatua*, *Polygonum convolvulus*, *P. bungeanum*, *Chenopodium album* and *Potamogeton distinctus*.

The areas at latitude 50-53 N. degrees. These areas are situated in north HelongJiang where the mean temperature is below 0°C. The major crops are potato and rape, the representative weeds are *Galeopsis bifid* and *Avena fatua*.

There are 53 million hectares of weed infestation areas in China, among them, 17 serious weeds were distributed all over or most of areas in China, such as *Echinochloa crusgalli*, *Digitaria sanguinalis*, *Chenopodium album*, *Polygonum lapathifolia*, *Avena fatua*, *Alopecurus aequalis*, *Cyperus rotundus*, *Potamogeton distinctus*, *Scirpus planiculmis*, *Juncellus serotina*, and more 30 major weeds such as *Galium aparine*, *Malachium aquaticum*, *Stellaria media*, *Portulaca oleracea*, *Leptchloa chinensis* and some weeds only infestation in partial areas such as *Dactyloctenium aegypiacum*, *Hedyotis costata* in tropic zone areas in south China, the *Galeopsis bifid*, *Polygonum convolvulus* in north China. The total grain yield loss cause by weed damage was estimated at 15 billion kg per year.

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METOSULAM - A NEW TRIAZOLOPYRIMIDINE SULFONANILIDE HERBICIDE FOR BROADLEAF WEED CONTROL IN WINTER CEREALS

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Summary. Metosulam, formulated as a 714 g/kg water dispersible granule (ECLIPSE** herbicide) is a new post-emergence broadleaf herbicide for use in winter cereals. Metosulam at 5 g/ha gives control of most species of the Brassicaceae (including wild radish (*Raphanus raphanistrum*)), amsinckia (*Amsinckia calycina*) and is active against most species of the Fabaceae. Metosulam gives useful suppression of a range of other broadleaf weeds, but has no effect on grasses, including annual ryegrass (*Lolium rigidum*) and wild oats (*Avena spp.*). Metosulam has a wide window of application (Zadoks 13-31) and has an excellent safety margin in wheat, barley, oats, triticale and cereal rye. Metosulam is compatible with most selective grass herbicides and cereal broadleaf herbicides.

INTRODUCTION

Metosulam, N-(2,6-dichloro-3-methylphenyl)-5,7-dimethoxy-1,2,4-triazo lo[1,5-a] pyrimidine-2-sulfonamide, (ECLIPSE** herbicide) is a new herbicide being developed by DowElanco Australia Limited for broadleaf weed control in winter cereals.

Metosulam is absorbed by roots and foliage of plants and translocated to growing points where it inhibits the enzyme acetolactate synthase (ALS) which is essential for synthesis of amino acids. This paper reports the results of efficacy trials and weed-free crop tolerance screens conducted throughout the major winter cropping regions of Australia from 1988 to 1992.

METHODS

Formulation and Adjuvants. With the exception of initial field screens in 1988, all trials were conducted with a water dispersible granule (W.D.G.) of metosulam. Applications were made with either a non-ionic surfactant (e.g. AGRAL 600 @ 0.1% v/v) or an emulsifiable crop oil (UPTAKE** @ 0.5% v/v).

Efficacy trials conducted on commercial growers' properties using natural weed infestations were laid in a randomised complete block design with three or four replicates. Small-plot trials were applied using a propane-powered AZO precision back-pack sprayer with a hand-held boom (2 or 3 metres long) fitted with flat fan nozzles at 50 cm centres. At an operating pressure of 200 kPa, 100 L/ha of spray solution was applied. Larger plots were treated using a motorbike-mounted sprayer with a 6 metre boom fitted with flat fan nozzles and at 200 kPa operating pressure, 50 L/ha of spray solution was applied.

Weed-free crop tolerance screens were established in representative agronomic areas over at least two seasons and using major commercial crop cultivars.

Plantback trials were conducted over two years in which metosulam at up to 40 g/ha (eight times the proposed label rate) was applied to bare soil and rotational crops sown into the plots.

** ECLIPSE and UPTAKE are trademarks of DowElanco Australia Ltd.

RESULTS AND DISCUSSION

Weed control (biomass reduction) was assessed visually at 2,4 and 6 weeks post-treatment and final control levels are summarised and presented in Tables 1,2 and 3.

Metosulam 5 g/ha, applied to weeds which ranged is size from 2-4 leaf to 8-10 leaf, controlled most species of the Brassicaceae including wild radish (*Raphanus raphanistrum*), Indian hedge mustard (*Sisymbrium orientale*), turnip weed (*Rapistrum rugosum*), ball mustard (*Neslia paniculata*) and wild turnip (*Brassica tournefortii*).

Table 1. Metosulam for control (%) of wild radish (RAPRA), Indian hedge mustard (SSYOR), turnip weed (RASRU), ball mustard (NEAPA) and wild turnip (BRSTO).

Herbicide	Rate (g/ha)	RAPRA	SSYOR	RASRU	NEAPA	BRSTO
metosulam*	3.6	93 (11) [75-100]	90 (2) [80-100]	85 (6) [70-95]	73 (2) [60-87]	-
metosulam*	5.0	96 (13) [83-100]	91 (3) [80-100]	83 (1)	88 (2) [85-90]	-
metosulam#	5.0	91 (50) [75-100]	81 (24) [60-100]	91 (18) [70-100]	86 (3) [82-90]	84 (3) [75-100]
metsulfuron#	3.0	-	87 (15) [47-100]	98 (7) [93-100]	90 (3) [85-95]	88 (2) [75-100]
2,4-D$	750/400	86 (8) [76-100]	-	100 (4)	-	-

* UPTAKE oil @ 0.5% v/v.
\# AGRAL 600 wetter @ 0.1% v/v.
$ 2,4-D amine at 750 g a.e./ha or 2,4-D ester at 400 g a.e./ha.

( ) No. of trials summarised
[..] Range of means

Metosulam, 5 g/ha with wetting agent applied to weeds which ranged in size from 2-10 leaf (or from 2-4 whorl GALTC), controlled amsinckia (*Amsinckia calycina*) and gave useful suppression of sheepweed (*Lithospermum arvense*), threehorn bedstraw (*Galium tricornutum*), capeweed (*Arctotheca calendula*) and doublegee (*Emex australis*). On this group of weeds, wetting agent tended to give better enhancement of weed control than UPTAKE oil.

Metosulam 5 g/ha was active against certain species of the Fabaceae, including volunteer field peas (*Pisum sativum*), medics (*Medicago spp.*) and subterranean clover (*Trifolium subterraneum*), however lupins (*Lupinus angustifolius*) were highly tolerant.

Metosulam had no effect on grasses, including annual ryegrass (*Lolium rigidum*) and wild oats (*Avena spp.*).

Metosulam shows promising compatibility with selective grass herbicides (aryloxyphenoxypropionates and cyclohexanediones) and cereal broadleaf herbicides including sulfonylureas, hydroxybenzonitriles, phenoxy acid derivatives, ureas and triazines.

Selectivity to winter cereals. In eight weed-free crop tolerance screens conducted from 1989 to 1991 metosulam , was safe to all thirty three varieties of wheat and nine varieties of barley tested (see Table 4). In addition, metosulam at up to twice the maximum proposed label rate was safe to oats (5 varieties), triticale (3 varieties) and one variety of cereal rye.

Table 2. Metosulam for control (%) of amsinckia (AMSCA), sheepweed (LITAR), bedstraw (GALTC), capeweed (AROCA) and doublegee (EMEAU)

Herbicide	Rate (g/ha)	RAPRA	SSYOR	RASRU	NEAPA	BRSTO
metosulam*	3.6	80 (1)	50 (2) [30-70]	52 (2) [50-53]	39 (6) [43-68]	30 (1)
metosulam*	5.0	83 (1)	58 (2) [40-75]	66 (2) [57-75]	47 (10) [33-98]	48 (6) [53-60]
metosulam#	5.0	86 (7) [70-97]	63 (6) [37-100]	77 (6) [67-87]	47 (34) [10-92]	49 (18) [38-90]
metsulfuron#	3.0	91 (4) [0-100]	62 (6) [30-95]	64 (4) [57-70]	15 (14) [0-45]	80 (13) [48-100]

* UPTAKE oil @ 0.5% v/v. ( ) No. of trials summarised
\# AGRAL 600 wetter @ 0.1% v/v. [..] Range of means

Table 3. Control (%) of volunteer peas (PIBST), medics (MEDSP) and subterranean clover (TRFSU) with metosulam

Herbicide	Rate (g/ha)	PIBST	MEDSP	TRFSU
metosulam*	3.6	79 (3) [72-85]	67 (2) [55-78]	-
metosulam*	5.0	79 (3) [72-85]	80 (2) [80]	100 (1)
metosulam#	5.0	71 (7) [53-93]	72 (7) [50-93]	89 (4) [77-100]
metsulfuron#	3.0	78 (5) [48-100]	90 (5) [77-98]	93 (4) [90-98]

* UPTAKE oil @ 0.5% v/v. ( ) No. of trials summarised
\# AGRAL 600 wetter @ 0.1% v/v. [..] Range of means

Metosulam also showed promising selectivity to lupins.

Crop Rotation Intervals. Six trials were established in the southern cereal growing regions of Australia in which susceptible rotational crops (field peas, medics, subterranean clover and vetch) were planted into plots treated 10-12 months earlier with up to 20 g/ha metosulam (four times the maximum proposed label rate). All crops emerged with no sign of metosulam damage.

Two further trials were conducted on black clay soils (Breeza Plains, NNSW) in which susceptible crops were planted one to sixteen weeks after application of metosulam to bare soil. For successful establishment of canola and sunflowers, at least two months plantback interval was required.

Table 4. Cereal yields (expressed as a percent of the untreated control) from weed-free crop tolerance screens 1989-1991.

Rate of metosulam# (g/ha)	Crop stage at treatment (Zadoks)		
	Zd 13-15	Zd 13,22-22,23	Zd 30-31
Wheat			
5.0	98.1 [8.8]	100.3 [6.2]	103.8 [12.2]
10.0	97.9 [7.1]	98.8 [7.7]	102.8 [7.1]
No varieties tested	33	28	16
Barley			
5.0	101.2 [15.6]	105.3 [1.5]	104.0 [6.3]
10.0	99.4 [10.9]	107.0 [11.1]	105.0 [7.3]
No varieties tested	9	3	6

[ ] Standard deviation.
\# plus AGRAL 600 wetter @ 0.1% v/v.

Conclusion. Metosulam is a new post-emergence broadleaf herbicide for cereals offering the unique combination of excellent wild radish control, compatibility with grass and broadleaf herbicides, and the possibility of true one-pass weed control. It is safe to cereals and has acceptable plantback requirements for rotational crops.

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FLUMETSULAM - A NEW POST-EMERGENCE HERBICIDE FOR BROADLEAVED WEED CONTROL IN UNDERSOWN WHEAT AND IN MEDIC, SUB-CLOVER AND LUCERNE SEED CROPS AND PASTURES

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Summary. Flumetsulam is a new sulfonanilide herbicide being developed for post-emergence broadleaved weed control in undersown wheat and certain legume crops and pastures. Indian Hedge mustard (*Sisymbrium orientale*), wild turnip (*Brassica tournefortii*), ball mustard (*Neslia paniculata*), wild radish (*Raphanus raphanistrum*), threehorn bedstraw (*Galium tricornutum*), and yellow burrweed (*Amsinckia calycina*) are controlled by flumetsulam at 16-20 g ai/ha. Crop tolerance studies show wheat from zadoks 12 to 31, medic and clover pre-emergence and post-emergence from two trifoliate leaf onwards and lucerne post-emergence from two trifoliate up to six trifoliate leaf are tolerant to flumetsulam at up to 40 g/ha. Plant back studies have shown that susceptible rotational crops including lupins, faba beans and canola can be safely planted six to thirteen months after an in-crop application of up to 30 g/ha flumetsulam.

INTRODUCTION

Flumetsulam, N-[2,6-difluorophenyl]-5-methyl (1,2,4) triazolo-[1,5a]-pyrimidine-2-sulfonamide, is being developed by DowElanco Australia Limited for broad-leaved weed control in undersown wheat crops and medic, sub-clover and lucerne pastures and seed crops.

Flumetsulam is a member of the sulfonanilide family. It is absorbed by both the roots and foliage of plants and translocated to the growing points where it acts by inhibiting the enzyme acetolactate synthase (ALS) which is essential for amino acid synthesis.

The relative susceptibility of plants to flumetsulam is a function of the time required for absorption and translocation and the rate of metabolism within the plant.

This paper summarises the spectrum of weeds controlled by flumetsulam, its selectivity to a range of crops and its safety to rotational crops. It briefly discusses the potential of flumetsulam for more effective legume pasture establishment in the cereal/pasture ley rotations practised in southern Australia.

METHODS

Formulation and adjuvants. Flumetsulam is formulated as a water dispersible granule containing 800 g/kg (BROADSTRIKE* herbicide). All applications were made with either a non-ionic surfactant (e.g. Agral® 600 or polyglycol 26-2 at 0.1% v/v) or with UPTAKE*, an emulsifiable crop oil, at 0.5% v/v.

Efficacy trials. Efficacy trials, laid in a randomised complete block design, were replicated three or four times, often with split timings of application. Treatments were applied using a gas-powered AZO small-plot sprayer with hand held boom fitted with flat fan nozzles at 50 cm centres, or with 4WD motorbike sprayers, applying 50-100 L/ha water volumes.

* Trademark of DowElanco
® Trademark of ICI PLC

<u>Weed free crop tolerance</u>. Weed free crop tolerance screens were established in representative agronomic areas covering at least two seasons and using major commercial crop cultivars.

<u>Plantback trials</u>. Plantback trials were conducted over two years in which flumetsulam at over two times the label rate was applied to bare soil and rotational crops sown into the plots.

RESULTS AND DISCUSSION

<u>Weed control</u> (biomass reduction) was assessed visually at 2, 4 and 6 weeks post-treatment and final ratings are presented in Table 1.

Table 1. <u>Weeds up to 5 cm diameter</u>. Mean visual percent weed control (biomass reduction by flumetsulam of Indian hedge mustard (IHM), wild turnip (WT), ball mustard (BM), wild radish (WR), bedstraw (B), turnip weed (TW) and yellow burrweed (YB). Mean of two to nine sites per species. (Standard deviation underneath in brackets)

	Rate g/ha	IHM	WT	BM	WR	B	TW
Flumetsulam¯	16	83.7	-	-	79.5	75.0	-
		(4.7)			(16.6)	-	
	20	94.7	91.7	88.1	87.0	91.7	97.0
		(4.1)	(11.8)	(9.7)	(10.7)	(10.3)	(5.1)
	32	-	-	-	94.9	-	-
					(7.6)		
Flumetsulam*	16	91.7	-	-	77.4	82.0	97.5
		(5.7)			(19.9)		(3.5)
	20	96.7	97.5	97.2	83.4	92.7	97.5
		(4.4)	(3.5)	(2.5)	(18.1)	(6.7)	(3.9)
	32	-	-	-	98.2	-	-
					(19.6)		
Diflufenican	100	93.9	-	-	82.6	-	-
		(2.7)			(12.2)		
MCPA sodium	175	79.3	75.9	53.9	65.6	-	83.3
		(6.6)	(8.3)	(39.3)	(15.8)	-	

¯ Plus Agral 600 at 0.1% v/v
* Plus Uptake (surfactant/oil) at 0.5% v/v

Flumetsulam at 16-20 g/ha gave commercially acceptable control of Indian hedge mustard (*Sisymbrium orientale*), wild turnip (*Brassica tournefortii*), ball mustard (*Neslia paniculata*), wild radish (*Raphanus raphanistrum*), threehorn bedstraw (*Galium tricornutum*) and yellow burrweed (*Amsinckia calycina*).

Flumetsulam was generally more effective as an early post-emergence application (weeds up to 5 cm diameter Table 1) than at a later application to larger weeds (5-10 cm diameter Table 2).

This was most marked with Indian hedge mustard and wild turnip, with bedstraw being the exception such that better control resulted from later applications.

On Indian hedge mustard, wild turnip and ball mustard, flumetsulam was more effective when applied with UPTAKE at 0.5% v/v than when applied with AGRAL 600 at 0.1% v/v. On wild radish, bedstraw and turnip weed, flumetsulam gave comparable levels of control irrespective of adjuvant.

Table 2. Weeds 5 cm to 10 cm diameter. Mean visual percent weed control (biomass reduction by flumetsulam of Indian hedge mustard (IHM), wild turnip (WT), ball mustard (BM), wild radish (WR), bedstraw (B), turnip weed (TW) and yellow burrweed (YB). Mean of two to nine sites per species. (Standard deviation underneath in brackets)

	Rate g/ha	IHM	WT	WR	B	TW	YB
Flumetsulam⁻	16	74.3	-	75.0	83.2	-	66.5
		(6.3)		(14.9)	(7.3)		(19.1)
	20	81.7	73.9	79.2	92.2	90.4	85.5
		(11.1)	(23.3)	(18.9)	(5.5)	(8.1)	(15.0)
	32	-	76.5	96.1	-	95.3	
			(19.1)	(5.5)		(4.7)	
Flumetsulam*	16	82.2	95.0	76.8	90.2	-	75.0
		(8.5)	-	(13.9)	(2.6)		(7.0)
	20	85.1	88.2	83.0	93.7	90.5	76.7
		(10.9)	(13.8)	(13.3)	(5.0)	(7.7)	(16.0)
	32	-	89.0	96.7	-	94.6	-
			(8.5)	(4.4)		(4.8)	
Diflufenican	100	83.7	85.0	78.1	-	-	-
		(13.6)	-	(11.7)			
MCPA sodium	175	65.2	64.0	56.9	-	85.4	-
		(26.6)	(31.4)	(20.5)		(2.9)	

⁻ Plus Agral 600 at 0.1% v/v

* Plus Uptake (surfactant/oil) at 0.5% v/v

Flumetsulam has shown poor activity on capeweed (*Arctotheca calendula*), soursob (*Oxalis pes-caprae*), fumitory (*Fumaria densiflora*) and moderate activity on white iron weed (*Lithospermum arvensis*).

Wheat tolerance. In seven multi-variety weed free crop tolerance screens conducted in 1991 and 1992, flumetsulam was safe to all varieties of wheat tested. (Table 3) Treatments were applied at zadoks 12-13, 14-15/21, 22 and 30-31, at 16 or 20 g/ha and also at 32 or 40 g/ha with either non-ionic surfactant at 0.1% v/v or a Uptake at 0.5% v/v. Flumetsulam shows a high margin of selectivity up to 40 g/ha irrespective of adjuvant.

Medic, Sub-clover and Lucerne Crop Tolerance. In 1991, flumetsulam was included in a medic and lucerne crop tolerance screen at the Victorian Institute for Dryland Agriculture (1).

Parabinga, Parragio *(M. truncu lata)*, Circle Valley and Santiago *(M. Polymorpha)* medics as well as CUF 101 lucerne *(M. sativa)* were included and flumetsulam was applied at 20 g/ha. Flumetsulam did not significantly reduce medic burr production (relative to hand weeded controls) in any variety except Parabinga where the yield was comparable with that of the unsprayed control. Lucerne persistence as measured in February (plants/m^2) showed that flumetsulam was one of the most selective herbicides.

Table 3. Wheat grain yield expressed as a percent of untreated control from seven weed free multi-variety crop tolerance screens in 1991 and 1992 (Standard deviation in brackets, where more than one screen)

	Rate g/ha	Crop growth stage at treatment		
		Zadoks 12-13	Zadoks 14-15/21-22	Zadoks 30-31
Flumetsulam[-]	16	99.8 (6.4)	-	-
	20	99.0	95.9 (6.4)	100.4 (2.3)
	32	97.6 (6.9)		
	40	95.9	89.8	98.5 (4.0)
Flumetsulam[#]	16	98.8 (4.1)		99.1 (5.2)
	20			
	32	97.5 (3.5)		101.0 (3.8)
	40			
No of varieties tested		18	12	18

[-] Plus non-ionic surfactant at 0.1% v/v
[#] Plus Uptake (surfactant/oil) at 0.5% v/v

In 1991 and 1992, flumetsulam was included in a medic, sub-clover and grain legume screen at Hart in South Australia (2). Pre and post-emergence applications of flumetsulam at 20 and 40 g/ha were selective to the cultivars screened.

In 1992, flumetsulam was applied pre and post-emergence to lucerne (Aurora) in Northern New South Wales. Flumetsulam at 20 g/ha applied pre-emergence was unacceptably damaging, but post-emergence application (with UPTAKE at 0.5% v/v) at the two and 6 leaf growth stages showed good selectivity as measured by fresh weight cuts.

Soil Persistence and Rotational Crop Restrictions. Flumetsulam is metabolized by soil microorganisms. Herbicide half life has ranged from less than one month up to two months under varying conditions. Availability in soil is primarily dependent upon soil pH and organic matter and herbicidal activity increases as pH increases and organic matter decreases.

Flumetsulam was applied to a red-brown earth in southern New South Wales in 1990 at rates of up to 75 g/ha, more than twice the proposed maximum use rate in winter crops (32 g/ha).

Susceptible crops (lupins, faba beans and canola) sown into these treatments six months later were unaffected.

At two sites in South Australia, flumetsulam was applied at 10, 20 and 30 g/ha. Rotational crops including vetch, sub-clover, medic, barley, wheat, canola and lupins were sown thirteen months later in 1991. No damage was observed in any crop at any rate.

In 1991 at two sites in South Australia, flumetsulam was applied at 10, 20 and 40 g/ha and rotational crops sown two to three months later.

At 20 g/ha at the Moonta site there was no damage to any crop, but the 40 g/ha rate caused slight damage to canola.

At the Clare site, 20 g/ha caused slight damage to vetch but moderate damage to canola.

Conclusion. Flumetsulam shows particular promise for weed control both in undersown wheat crops and in medic, sub-clover and lucerne based pastures and seed crops. Trial results indicate that early post-emergence use in cereals or pasture will not pose a threat to rotational crops grown nine to ten months later.

Taking into account the drive towards sustainable systems, there is now much more focus on establishing high quality legume dominant pastures as part of the cereal/pasture ley rotation. Successful legume pasture establishment relies on use of herbicides that provide effective weed control for the final cereal crop but are not damaging to the undersown pasture component. The wheat, medic, sub-clover and lucerne selectivity shown by flumetsulam will allow grain growers the option of better pasture establishment following the final wheat crop in a rotation.

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AC 322,140--A NEW BROAD-SPECTRUM HERBICIDE FOR SELECTIVE WEED CONTROL IN TRANSPLANTED AND WATER-SEEDED RICE

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Summary. AC 322,140 is a sulfamoylurea herbicide that selectively controls a wide range of weeds in transplanted and direct-seeded rice. The mode of action of AC 322,140 is via inhibition of acetohydroxyacid synthase (AHAS). Rice tolerance to AC 322,140 is primarily due to the rapid rate of metabolism of the herbicide. Laboratory studies using ^{14}C-AC 322,140 indicate moderately tight binding to soil and low potential for leaching. This new herbicide will provide a useful addition for weed control in rice, with excellent safety to the environment.

INTRODUCTION

Physical and chemical properties. AC 322,140 (1-{[O-(cyclopropylcarbonyl)phenyl]sulfamoyl}-3-(4,6-dimethoxy-2-pyr imidinyl)-urea) is a sulfamoylurea. It differs from the sulfonylurea class of herbicides both in the chemistry of the urea bridge and the cyclopropyl ketone substitution on the phenyl ring. It is an off-white solid with a melting point of 170-171°C and a molecular weight of 422. AC 322,140 is soluble in most organic solvents and insoluble in water, with the water solubility and octonol/water partition coefficients affected by pH (Table 1). Hydrolysis studies using 0.1 M ^{14}C-labeled AC 322,140 in 50 mM phospate buffer indicate that hydrolysis is greatly affected by pH (Table 1). AC 322,140 undergoes rapid hydrolytic urea bridge cleavage at lower pH.

Table 1. Effect of pH on apparent octanol/water partition coefficient (K_{ow}), water solubility, and hydrolysis of AC 322,140

Parameter measured	pH				
	3	5	6	7	8
Apparent K_{ow} at 25C	38	111	49	26	5
Water solubility at 25C (in ppm)[a]		<1	3	6	32
Hydrolysis in 50 mM phosphate buffer half life (days)	2.2	2.2	5.1	40[b]	91[b]

[a] Water solubility was determined in preliminary studies using test material which was approximately 92% pure by the current analytical methodology. These results may be different when higher purity material is tested.
[b] Values for hydrolysis half-life at pH 7 and 8 were extrapolated from a 0 to 21 day hydrolysis study.

Toxicology. AC 322,140 has been shown to be very safe to mammals and other animals. In tests with technical material, the acute oral LD_{50} in rats was >5000/kg, the acute dermal LD_{50} in rabbits was >4000/kg, and the carp 48-hour LC_{50} was >10 ppm. It was mildly irritating to rabbit eyes with complete eye recovery within 48 hours. In microbial mutagenicity assays AC 322,140 was non-mutagenic. Long term toxicology studies are in progress.

Mode of action. The herbicidal activity of AC 322,140 is due to inhibition of acetohydroxyacid synthase, a key enzyme in amino acid biosynthesis. AC 322,140 has an I_{50} value of < 1 M.

Field performance of AC 322,140 in rice. AC 322,140 has been extensively field tested in rice, *Oryza sativa*, by American Cyanamid and its subsidiaries for the past 3 years, in a total of over 300 field trials throughout the world. In transplanted rice tests, AC 322,140 at 20 to 60 g ai/ha applied 0 to 15 days after transplanting controls many weed species, including the perennial weeds *Cyperus serotinus, Eleocharis congesta, E. kuroguwai, Sagitaria pygmaea, S. trifolia*, and *Scirpus juncoides*, and the annual weeds *Cyperus difformis, Elatine triandra, Lindernia augustifolia, L. procumbens, Monochoria vaginalis*, and *Rotala indica*(1). Grass weeds such as *Echinochloa crus-galli* are suppressed but not consistently controlled. AC 322,140 has also shown good control of broadleaf and sedge weeds and crop tolerance in water-seeded rice, applied 0 to 12 days after seeding at rates of 10 to 40 g/ha.

MATERIALS AND METHODS

Uptake, distribution, and metabolism of AC 322,140 by rice. The uptake, distribution, and metabolism of ^{14}C-AC 322,140 was evaluated in a series of experiments using hydroponics. Plants were transferred to a hydroponic nutrient solution containing ^{14}C-AC 322,140 when they had 2-3 leaves. Plants were harvested 2, 4, 24, 48 and 72 hours after treatment and divided into roots and shoots. Some plants were autoradiographed, while some plants were used to determine total radiolabel absorbed (combustion followed by liquid scintillation counting). Metabolism was evaluated by extraction of root and shoot tissue and chromatography (TLC and HPLC).

Leaching studies in 3 Japanese paddy soils. Leaching of ^{14}C-AC 322,140 was evaluated using square plexiglass columns packed with soil 8-10 cm deep with 100 cm^2 of soil surface area. Three Japanese rice paddy soils were evaluated. Columns were saturated with water and ^{14}C-AC 322,140 was applied directly to the soil surface. Three cm of water (300 mL total volume) per day were leached through the column over a two day period. Columns were drained to field capacity and sectioned into 1 cm slices. Soil sections were dried, oxidized, and radioactivity determined.

Combination leaching/plant uptake and distribution study. An experiment similar to the leaching study described above was conducted except that rice and several weed species were transplanted into the soil column. The soil column was packed with an alluvium sandy loam soil, saturated with water, and the following were planted into the column: 3 rice transplants (3.3 leaves, 30 cm tall), 4 *Saggitaria pygmaea* plants (0.4 cm tall), 4 *Cyperus serotinus* plants (4 cm tall), and 6 *Echinochloa crus-galli* plants (1.8 leaves, 4 cm tall). After three days, water was added to 2 cm above the soil surface. On the following day ^{14}C-AC 322,140 was added by pipette to the flood water. Water was leached through the column at the rate of 1 cm per day for two days after herbicide was added, with the flood height maintained at 2 cm above the soil level. Then plants were removed and sectioned (at about 2 cm intervals), columns were drained, and soil was sectioned into the top 3 cm vs the bottom 5 cm of soil.

Soil organic carbon partition coefficients for AC 322,140 and bensulfuron-methyl. Freundlich adsorption/desorption isotherms were obtained for AC 322,140 and bensulfuron-methyl using a batch-slurry method in 3 Japanese rice paddy soils and one U.S. soil (Sassafras sandy loam). Each herbicide was evaluated at four concentrations per soil for each of two adsorption periods. K_f (Freundlich adsorption) values were determined for each soil and condition and the K_{oc} (Soil organic carbon partition coefficient) was calculated by dividing each K_f by the percent organic carbon of the soil.

RESULTS AND DISCUSSION

Uptake, distribution, and metabolism of AC 322,140 by rice. In a hydroponic system, rice seedlings readily absorbed AC 322,140. Although the greatest concentration of radiolabel was in the roots, radiolabel was rapidly translocated throughout the plant. In shoots, the greatest concentration of ^{14}C-label was in the leaf margins and leaf tips. Metabolism of AC 322,140 was much faster in the shoots than in the roots. The half-life for metabolism of AC 322,140 was less than 2 hours for shoots compared to 24 hours for roots. Metabolism of AC 322,140 by rice was by urea bridge cleavage to yield herbicidally inactive compounds. This is quite different from the metabolism of bensulfuron-methyl by rice. Bensulfuron-methyl is metabolized by rice via hydroxylation of the methoxy substituent followed by demethylation (2).

Leaching studies in 3 Japanese paddy soils. For each soil, over 86% of the total radioactivity remained in the top 3 cm of soil. Radioactivity in the leachate was less than 1% (0.3% on alluvium sandy loam, 0.4% in volcanic loam, 0.7% in deluvium loam). These results show the low soil mobility of AC 322,140 (Table 2).

Table 2. Leaching of AC 322,140 in 3 Japanese paddy soils (3 cm leaching/day for 2 days)

Soil section (cm from surface)	Percent totla ^{14}C radioactivity		
	Alluvium sandy loam	Volcanic loam	Deluvium loam
0-1 cm	55.5	51.3	35.9
1-2 cm	25.9	21.8	36.5
2-3 cm	10.0	16.8	13.9
3-4 cm	4.9	7.9	2.8
4-5 cm	2.1	1.5	2.1
5-10 cm	1.3	0.3	8.2
Leachate	0.3	0.4	0.7

Combination leaching/plant uptake and distribution study. An experiment similar to the leaching study described above was conducted except that rice and several weed species were transplanted into the soil column. In this study, the distribution of radiolabel from ^{14}C-AC 322,140 as percent of applied was as follows: 7.5% in the 2 cm of flood water over the soil surface; 64% in the top 3 cm of soil; 26% in the lower 5 cm of soil; and 2.5% taken up by plants. More herbicide was found below 3 cm in this study when compared to the previous soil leaching study because some mixing of soil occurred when plants were removed.

All three weeds had a greater concentration of ^{14}C-AC 322,140 (per g dry weight) than rice. In the 3 weed species, over 85% of the radiolabel remained in the parts of the plant exposed to the top 3 cm of soil or the 2 cm of flood water (Table 3). In rice, only 47% of the radiolabel was in parts of the rice plant exposed to the top 3 cm of soil or flood water, while 40% had translocated to shoot tissue above the flood.

Metabolism studies in rice described above indicate that AC 322,140 translocated into shoot tissue is rapidly metabolized. In addition, most of the roots of rice plants are located deep enough in the soil that there is little exposure to the herbicide. Thus tolerance of rice to AC 322,140 is due to rapid metabolism to inactive compounds and location of most rice roots below the area of highest herbicide concentration. Rice also showed reduced uptake of herbicide compared to these weed species.

Table 3. Distribution of ^{14}C-AC 322,140 within each plant species in combination leaching/plant uptake study

Location of plant tissue	Rice	*S. pygmaea*	*C. serotinus*	*E. crus-galli*
	(% of total radiolabel)			
Shoot above flood	40.3	1.1	4.2	10.8
Herbicide zone (flood + top 3 cm)	47.2	98.8	95.7	88
Roots in bottom 3-8 cm of soil	12.5	0.2	0.4	1.3

Soil organic carbon partition coefficients for AC 322,140 and bensulfuron-methyl . AC 322,140 had K_{oc} values of 1530-5530 following a 1 day adsorption period (Table 4). This indicates that AC 322,140 binds tightly to soil. In all cases, the K_{oc} for AC 322,140 was higher than for bensulfuron-methyl, indicating that AC 322,140 binds to soil more tightly than bensulfuron-methyl.

Table 4. Comparison of soil adsorption constants of AC 322,140 and bensulfuron-methyl in 3 Japanese paddy soils and one U.S. soil, after a 1 day adsorption period

Soil type	Soil origin	pH	% O.M.	AC 322,140	bensulfuron-methyl
				(K_{oc} (L/kg))	
alluvium sandy loam	Kagawa	6.0	2.8	2,420	1,350
deluvium loam	Toyokawa	5.9	3.0	2,110	1,250
volcanic loam	Tochigi	5.5	10.4	1,530	1,380
sassafras sandy loam	New Jersey	6.6	1.2	5,530	2,790

AC 322,140 is a useful new tool for weed control in rice. Its low level of toxicity to animals, immobility in the soil, and excellent level of weed control and rice tolerance will provide farmers with good weed control with a low level of environmental risk. This new herbicide has also shown potential for broadleaf weed control in wheat and barley.

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CYHALOFOP BUTYL: A NEW GRAMINICIDE FOR USE IN RICE

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Summary. Cyhalofop butyl (proposed) ((R)-butyl 2- (4-(4-cyano-2-fluorophenoxy)phenoxy) propionate) is a new selective rice graminicide. Selectivity is due to differential metabolism of the molecule by rice and target grass weeds. The mechanism of action of cyhalofop butyl is inhibition of acetyl CoA carboxylase (ACCase). Cyhalofop butyl possesses a number of favorable toxicological, environmental and physical property features such as acceptable mammalian and aquatic toxicological profiles, lack of soil mobility, and rotational crop selectivity. These features permit its use in diverse rice cultural practices, including transplanted paddy and direct seeded rice.

INTRODUCTION

Cyhalofop butyl is a new post-emergence aryloxyphenoxy propionate graminicide discovered by DowElanco which controls a broad spectrum of grass weeds, including species of *Echinochloa, Brachiaria, Cynodon, Digitaria, Eleusine, Leptochloa, Panicum, Setaria, and Sorghum.* Cyhalofop butyl, coded XDE 537 or DEH 112, is highly selective to both *japonica* and *indica* rice varieties as well as to all broadleaf rotational crop species. It has a broad window of application (1-4 leaf barnyard grass) as well as the ability to mix with a number of other herbicides. This paper describes chemical, physical, toxicological and biological properties of the molecule.

METHODS

Greenhouse studies - paddy injection studies. A stock solution was prepared by dissolving technical cyhalofop butyl in acetone and bringing the solution to volume in 0.1% (v/v) TWEEN 20. Desired application rates were achieved by injecting measured volumes of stock solution into the flood water of plastic cups containing appropriate plant species germinated in puddled soil. Control plant cups were injected with solvent blanks. Water was not added to paddy cups for 2 days following injection, after which flood levels were maintained at a depth of 2-3 cm. Plants were grown in a glasshouse maintained on a 30°C day/26°C night temperature regime and a 16 h photo period (natural light was supplemented as necessary with multi vapor lamps). Visual assessment of herbicide activity and crop tolerance was made 3-4 weeks after treatment. The assessment was based on a comparison of treated plants to untreated control plants and used an evaluation scale of 0% (no effect) to 100% (complete kill).

Greenhouse studies - foliar applications. A 24% EC formulation of cyhalofop butyl was prepared in 0.25% (v/v) ORTHO X-77 surfactant and applied to test plants with a track sprayer (160 L/ha). Plants were grown in conventional horticultural pots under dryland (non-puddled soil) conditions. Control plants were sprayed with a solvent blank. Plant culture and test evaluation conditions were as above.

Calculations. GR 5 and GR80 values correspond to the rate required to give 5% and 80% control, respectively of the species listed in Tables 3 and 4. The data is calculated from a log rate vs. probit transformation of the percent growth control raw data.

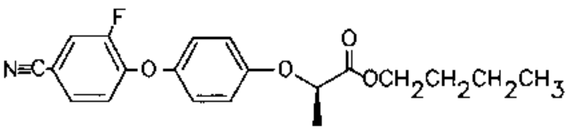
ACCase enzyme assay. ACCase was extracted from maize (*Zea mays*) and assayed by determining the acetyl CoA-dependent incorporation of $H^{14}CO_3^-$ into acid and heat stable products (1).

Plant metabolism studies. Plant metabolism studies were conducted using ^{14}C-labelled methyl ester (ME) of cyhalofop. ^{14}C-labelled cyhalofop ME was formulated in 50% acetone, 0.1% X-77 and 0.3% AGRI-DEX crop oil concentrate and applied in 0.5 µl droplets to the first true leaf of rice or barnyardgrass. The application rate was 50 g/ha at 200 L/ha. Treated plants were maintained in a growth chamber at 20°C or 30°C, 14 h photoperiod.

RESULTS AND DISCUSSION

Chemical and physical properties

Code name:	XDE 537, DEH 112
Common name:	Cyhalofop butyl
Chemical name (IUPAC):	(R)-butyl 2-(4-(4-cyano-2-fluorophenoxy) phenoxy)-propionate
Empirical formula:	$C_{20}H_{20}FNO_4$
Molecular weight:	357.39
Structural formula:	



Appearance:	odourless, white, crystalline solid	
Melting point:	50°C	
Solubility (at 20°C):	Water:	0.7 ppm (pH 7.0)
	Xylene:	47.3 (wt% a.i.)
	Acetone:	60.7 (wt% a.i.)
Octanol-water partition coefficient (logP):	3.31	
Vapor pressure:	8.8×10^{-9} mmHg at 20°C	

Toxicology. In reverse mutation tests (Ames test), in DNA repair assays, and in micro nucleus test in mice, cyhalofop butyl was determined to be non-mutagenic. In *in vitro* cytogenetics studies with cyhalofop butyl, no induction of structural chromosomal aberration was observed. Rat and rabbit studies indicated that cyhalofop butyl is not teratogenic.

The acute toxicity of cyhalofop butyl is considered to be low; results are summarized in Tables 1 and 2 below. Additional testing is in progress.

Table 1. Mammalian toxicological characteristics of cyhalofop butyl

Species	Route	Median lethal dose (mg/kg)
rat, male	acute oral	>5000
rat, female	acute oral	>5000
mouse, male	acute oral	>5000
mouse, female	acute oral	>5000
rat, male	acute dermal	>2000
rat, female	acute dermal	>2000

Table 2. Aquatic toxicological characteristics of cyhalofop butyl

Species	Route	LC_{50} (mg/L)
Japanese carp	aqueous	1.54
Rainbow trout	aqueous	1.65
Daphnia	aqueous	>100

Environmental stability. Cyhalofop butyl is stable at pH 4 but is hydrolyzed slowly at pH 7. At pH 1.2 or 9, cyhalofop is rapidly decomposed.

Mode of action. Cyhalofop butyl is a member of the aryloxyphenoxy propionate class of herbicides. Like the majority of the compounds in this class, cyhalofop butyl is readily absorbed by plant tissue, is phloem mobile and accumulates in the meristematic region of the plant (W. R. Bauriedel and J.H. Miller, DowElanco internal report). In addition, cyhalofop (acid) is an inhibitor of ACCase, which catalyzes the first committed step in fatty acid biosynthesis (1). The dose response of cyhalofop (acid) on maize ACCase activity is shown in Fig. 1 below. In this test, the I_{50} for cyhalofop (acid) is approximately 2 ppm.

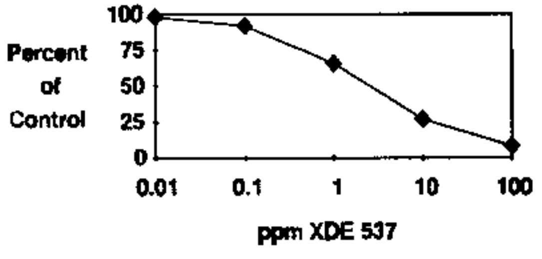


Figure 1. Dose-dependent inhibition of maize ACCase by cyhalofop (acid).

Plant metabolism. Rice tolerance to cyhalofop ME is due to both a rapid metabolism to the inactive diacid ($t_{1/2}$<10 h at 30°C) and to subsequent formation of nonpolar metabolites at $t_{1/2}$>10 h at 30°C. Conversely, barnyard grass sensitivity was attributed to rapid metabolism of the ester to the biologically active acid (85% conversion at $t_{1/2}$<10 h at 30°C).

Greenhouse studies. Cyhalofop butyl controls a broad spectrum of grass weeds while maintaining an excellent margin of crop selectivity. Tables 3 and 4 summarize the results of cyhalofop butyl activity applied in the flood or as a foliar treatment to annual grasses and to rice.

Rotational crop sensitivity. The following crop species showed no injury after 6 weeks of top watering with a solution of 2.4 ppm cyhalofop butyl: broccoli, carrot, corn, cotton, cucumber, eggplant, green pepper, lettuce, parsley, pea, soybean and tomato.

Soil properties. Soil metabolism studies indicate that cyhalofop butyl is rapidly metabolized under both flooded and upland conditions (both mineral soil and humic volcanic ash soil). In soil mobility studies, cyhalofop butyl is relatively immobile. When compared to the water front, cyhalofop butyl has an R_f = 0.22 in sandy soil and R_f= 0.35 in loamy soil.

Table 3. Annual grass control with cyhalofop butyl

Species	Flood water injection application GR 80 (g/ha)		Foliar application GR 80 (g/ha)
	1-2 leaf	3-5 leaf	1-3 leaf
Brachiaria platyphylla	35	351	50
Echinochloa crusgalli	59	544	170
Echinochloa colonum	--	--	87
Cynodon dactylon	--	118	158
Digitaria ischaemum	19	293	170
Eleusine indica	41	112	32
Leptochloa dubia	43	439	--
Leptochloa filiformis	--	--	150
Panicum dichotomiflorum	36	243	28
Panicum texanum	66	360	120
Setaria lutescens	71	383	146
Setaria viridis	--	35	237
Sorghum halepense	115	359	400

Table 4. Crop tolerance with cyhalofop butyl

Species	Flood water injection application GR 5 (g/ha)	Foliar application GR 5 (g/ha)
Oryza sativa	>400	>800

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DPX-PE350, A NEW POST-EMERGENCE HERBICIDE FOR COTTON

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Summary. The experimental herbicide DPX-PE350 was evaluated over 3 years (1990-92) for crop safety and post-emergence control of important broad-leaved weeds of cotton in Australia. DPX-PE350 was tested at rates between 25-200 g ai/ha and was found to be effective against Thornapple, *Datura* spp. at 25 g ai/ha, Sesbania pea, *Sesbania cannabinda*, Anoda weed, *Anoda cristata* and Boggabri weed, *Amaranthus mitchellii*, at 50 g ai/ha, Polymeria, *Polymeria pussilla* , Yellow vine and *Tribulus micrococcus*, at 75 g ai/ha, and Annual ground cherry, *Physalis angulata*, and Cowvine, *Ipomoea lonchophylla* at 100 g ai/ha and gave useful suppression of Noogoora burr, *Xanthium pungens* and Bathurst burr, *Xanthium spinosum* at 100 g ai/ha when applied as an early post-emergence treatment. A number of other weeds were also controlled or suppressed. The effect of DPX-PE350 on cotton was rate related and temporary, most pronounced at 100-200 g ai/ha and expressed as interveinal yellowing and biomass reduction.

INTRODUCTION

Post-emergent control of weeds in cotton is important as they reduce lint yield and quality and can interfere with harvesting. At present the number of post-emergence herbicides available for weed control in cotton is limited and their crop safety is marginal. Current weed control practices are ineffective against weeds such as Sesbania pea, Anoda weed and Thornapple. Weeds escaping control by pre-emergence herbicides, e.g. Burrs, Cowvine, Bellvine, *Ipomoea plebea* or weeds emerging later in the season continue to pose a problem for Australian cotton growers. Often, the only available method of weed control is by mechanical cultivation and hand chipping. The average cost of chipping over the last 3 years was close to $85.00/ha. Typically, the cotton industry spends approximately $50 million per annum on weed control and nearly 40% of this amount is spent on chipping weeds.

DPX-PE350 (pyrithiobac) is a new experimental herbicide first evaluated in Australia in 1990 as a selective herbicide for early post-emergence control of weeds in cotton. It represents a new family of chemistry which inhibits the enzyme acetolactate synthase, a key enzyme in the biosynthesis of branched chain amino acids (1). The herbicide is rapidly absorbed through foliage and to some extent by roots, blocking cell division and inhibiting growth in susceptible plants. Overseas data indicates both pre- and post-emergence activity for the control of broad-leaved and grass weeds (1). This paper reports on the results from 57 field trials conducted in Australia with the herbicide DPX-PE350 to determine its efficacy spectrum and crop safety when applied as a post-emergence treatment in cotton.

METHODS

Field trials were conducted in the major cotton producing regions of Australia in 1990, 1991 and 1992. Experimental sites were established in the Macquarie, Namoi, Gwydir and McIntyre Valleys of New South Wales and the Darling Downs, Lockyer Valley, St George and the Central Highlands areas of Queensland. While the trials were targeted against the economically important weeds of cotton such as Sesbania pea, Thornapple, Bathurst and Noogoora burr, Cowvine, Anoda weed, Caltrop, *Tribulus terrestris*, Yellow vine and Annual ground cherry, other species occurring in the trials were evaluated for their susceptibility. Most of the trials were conducted in irrigated cotton, however some were established under dryland conditions. DPX-PE350 was tested at rates between 25-200 g ai/ha. Where appropriate, standard treatments were included in the trials but they were too numerous and varied for the results to be presented in this paper. Often the standard treatment was hand chipping. Herbicide treatments were applied as early as practical, usually at cotyledon-4 leaf stage although in some trials weeds were more advanced. Crop stage was between 1 true leaf and early flowering. Trials were installed on the common commercial varieties DP90, Siokra L22, Siokra 5324, Siokra 1-4, Sicala 33, Sicala V1 and CS-189. The herbicide treatments were applied as a blanket spray using a 3 m hand-held boom, with Teejet 11001 and 11002 flat fan spray tips, at 250 Kpa pressure in 100-150 L/ha water. A non-ionic surfactant [Alcohol Alkoxylate] was added to all herbicide treatments at 0.25% v/v. Plots (3 or 4 rows x 15 m) were arranged in randomised complete blocks, replicated 3 or 4 times. Weed control was visually evaluated by using a linear rating system where 0 = no control and 100 = 100 % biomass reduction, at 1, 2-3 and 5-6 weeks post application. Crop phytotoxicity was assessed at the same times using a linear rating system where 0 = no injury and 100 = severe effect, 80-100% mortality. Individual trials were analysed using a two way analysis of variance, and the results presented in this paper are the mean of all available data.

RESULTS AND DISCUSSION

Weed control. Weed control expressed as % biomass reduction taken at the final assessment is given in Table 1.

DPX-PE350 at 25 g ai/ha gave excellent control of volunteer sunflower and thornapple, one of the most troublesome weeds in cotton. At this rate plants with up to 9 leaves or 30 cm high were controlled within 10 days of application. At 50 g ai/ha DPX-PE350 gave at least 95% biomass reduction of Boggabri weed and Sesbania pea up to 20 cm high and Anoda weed with up to 5 leaves. These weeds were controlled in 14-21 days. 75 g ai/ha was required to achieve good control of Polymeria and Yellow vine up to 15 cm in diameter. On 1-4 leaf Annual ground cherry and Cowvine and Sesbania pea up to 60 cm high 100 g ai/ha gave over 90% control. This rate also gave useful supression of up to 4 leaf Noogoora burr and Bathurst burr. Other species were less sensitive and at the highest test rate only supression was achieved. Two important weeds of cotton, Bladder ketmia and Nutgrass were not controlled. Application timing was more critical for some species (Burrs, Cowvine and Annual ground cherry) than others (Thornapple, Volunteer sunflower). While larger plants were initially suppressed, regrowth occurred and control dropped markedly when plants with more than 4 leaves were treated. Trial results indicate that for optimum weed control good soil moisture is essential, under dry conditions weeds were slower to respond and weed control was generally less satisfactory. Herbicide symptoms on susceptible species appeared within 5 to 10 days post treatment and varied between species. Most typical symptoms were chlorosis or browning of leaves and necrosis of growing points and stem followed by plant death. Inhibition of root development (root pruning) was observed on many species. Plants died within 7 to 28 days of application, depending on sensitivity and size. Early leaf drop was reported on sesbania pea and stem brittleness was observed in a number of species

Crop effect. The effect of DPX-PE350 on cotton was transient, rate related and influenced by crop stage. Crop phytotoxicity was commonly observed as biomass reduction and interveinal yellowing. Crop phytotoxicity recorded as % biomass reduction at the 1 week assessment is presented in Table 2.

Table 1. Weed control (% biomass reduction) by DPX-PE350 when applied as a post-emergence treatment

Species[a,b]		Treatments (g ai/ha)					
		25	50	75	100	150	200
Boggabri weed	[6]	85	95	96	99	100	100
Anoda weed	[3]		97	100	100	100	100
Wild melon	[1]		65	75	80	85	95
Nutgrass	[4]	0	6	8	21	32	37
Thornapple	[9]	99	100	100	100	100	100
Sunflower (volunteer)	[1]	100	100	100	100	100	100
Bladder ketmia	[3]		13	18	27	34	38
Barley (volunteer)	[1]	15	37	62	72	92	92
Yellowflower devil's claw	[1]		33	53	62	85	92
Cowvine	[5]			78	91	90	93
Bellvine	[3]		60	65	76	79	88
Sensitive plant	[1]	22	37	49	56		64
Annual ground cherry	[3]		87	88	92	92	96
Polymeria	[2]	77	84	96	98	99	100
Pigweed	[1]		26	36	41		60
Rhyncosia	[5]		28	40	43	41	57
Mintweed	[1]		64	71	71	75	76
Sesbania pea[c]	[8]	82	98	99	100	100	100
Sesbania pea[d]	[4]		82	84	95	94	95
Sida	[1]	68	70	100	100	100	83
Common sowthistle	[1]		43	60	83	92	83
Columbus grass	[2]		57	65	58	74	84
Black pigweed	[3]			47	58	61	69
Yellow vine	[5]	65	80	92	96	98	98
Caltrop	[2]		36	54	68	70	78
Maloga bean	[3]			44	50	45	62
Noogoora burr	[6]			74	81	83	85
Bathurst burr	[3]			59	76	85	88

[ ] Indicates the number of trials
[a] See Appendix for scientific names not given previously
[b] Application timing was cotyledon-4 leaf or up to 15 cm in diameter or in height for most species
[c] Up to 20 cm high
[d] 20-60 cm in high

As shown in Table 2 crop effect was most pronounced when young crops (cotyledon to 3 leaf) were treated. The level of biomass reduction observed on more advanced crops was less, particularly at the 25 to 100 g ai/ha rates. Biomass reduction however, was not observed in every trial. In the 25 to 100 g ai/ha rate range there was no crop effect reported in 23% of all trials and a further 35% of all trials had no more than 10% biomass reduction. The highest level of biomass reduction was 35%, recorded in one trial when DPX-PE350 was applied to a 2 leaf crop. Crop effects were temporary and crops fully recovered within 4 to 6 weeks, often sooner. Varietal differences did not appear to influence the level of phytotoxicity, this was confirmed by a specific tolerance screen (Agrisearch Pty Ltd, pers. comm., 1992). Other forms of crop phytotoxicity were also observed and described as interveinal yellowing, however bronzing and leaf burn were reported in 5 trials conducted on the Central Highlands. Interveinal yellowing was commonly evident in trials where biomass reduction was observed and it was usually the first symptom to appear, but was not reported in every trial. Symptoms lasted no more than 14 to 21 days and were not always rate related. It was most apparent on the top part of the plant where leaves were most exposed to the herbicide. Emerging new leaves were unaffected. Biomass reduction did not effect subsequent plant development and did not appear to delay maturity. Yield data and boll counts from 10 trials and from one tolerance screen (Agrisearch Pty Ltd, pers. comm., 1992) indicate no negative effect on yield at the highest test rate of 200 g ai/ha.

Table 2. Effect of DPX-PE350 on cotton when applied at various crop stages

Crop stages	% Biomass reduction DPX-PE350 g ai/ha					
	25	50	75	100	150	200
Cotyledon - 3 leaf	6.7 [7]	9.7 [18[	10.0 [19]	11.7 [24]	13.2 [16]	15.2 [23]
3-5 leaf	2.7 [4]	4.5 [15]	6.7 [15]	9.0 [17]	10.2 [15]	10.9 [14]
5 leaf - flowering	0 [2]	1.6 [5]	3.0 [10]	4.4 [11]	10.0 [7]	10.4 [9]

[] Indicated the number of trials.

APPENDIX

List of scientific names not given previously.

Wild melon, *Citrullus lannatus*
Barley (volunteer), *Hordeum vulgare*
Yellowflower devil's claw, *Ibicella lutea*
Sensitive plant, *Mimosa* spp.
Pigweed, *Portulaca oleracea*
Rhyncosia, *Rhyncosia minima*
Mintweed, *Salvia reflexa*
Sida, *Sida retusa*
Common sowthistle, *Sonchus oleraceus*
Columbus grass, *Sorghum x almum*
Black pigweed, *Trianthema portulacastrum*
Maloga bean, *Vigna lanceolata*

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THE MODE OF ACTION OF DIFLUFENICAN AND POSSIBILITIES FOR IMPROVEMENT OF POST-EMERGENCE ACTIVITY

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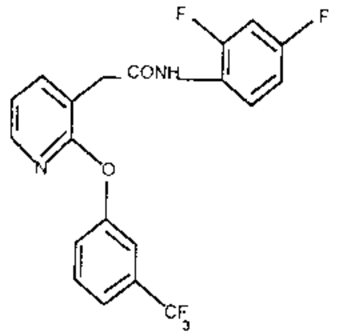
Summary. Diflufenican is a potent inhibitor of carotenoid biosynthesis active pre- and post-emergence. In post-emergence use the active is retained by the leaves but no useful phloem transport occurs. Trials showed that surfactants effective in reducing surface tension and increasing diflufenican solubility in the spray solution improved efficacy. Tankmixes of the diflufenican suspension concentrate plus MCPA emulsifiable concentrate were less efficacious than the co-formulated components. Beneficial effects of the solvents in the formulation are suggested to act as foliar penetration agents.

INTRODUCTION

Diflufenican (DFF) [N-(2,4-difluorophenyl)-2-(3-trifluoro-methylphenoxy)-3-pyridine carboxamide] is a member of the phenoxy nicotinanilide family (PNA) discovered in 1979 by Rhône-Poulenc Secteur Agro. The family is characterised by 3 essential rings:

- nicotine ring
- phenoxy ring attached at position 2
- carboxy anilinophenyl attached at position 3.



DFF has activity both as a pre-emergence and an early post-emergence herbicide. Its main activity is against broadleaf weeds but it also has interesting activity against certain important grass weeds. Susceptible species typically show symptoms of chlorosis and bleaching indicating that the major mode of action is on photosynthetic pigments.

Chlorophyll content is not affected directly by DFF since susceptible plants grown in dim light after treatment with DFF can accumulate more chlorophyll than similar plants grown in bright light (1).

The initial effect of DFF in affected tissues has been shown to be as a potent inhibitor of carotenoid biosynthesis causing accumulation of the carotenoid precursor phytoene. This indicates that the target site for DFF is the enzyme phytoene dehydrogenase, the target site of other bleaching herbicides such as norflurazn (2). DFF has no activity on pre-existing carotenoids and is most effective in growing tissues with rapid rates of carotenoid biosynthesis.

A major function of carotenoids is to protect chlorophyll and chloroplast membranes from photo-oxidation in bright light. The absence of carotenoids allows the photo-destruction of chlorophyll and causes the plant tissue to appear white, due to the absence of both carotenoid and chlorophyll pigments, showing the 'bleached' symptoms typical of DFF activity. A red pigmentation is often observed in DFF treated plants, especially grasses, due to stress induced anthocyanin production (3).

Pre-emergence activity. DFF is relatively immobile in soil due to adsorption and its low water solubility (log Kow = 4.9, water solubility = 0.01 µg/mL) and the majority is held in the top 1-2 cm of soil. The persistence of DFF in soil, combined with its low mobility is sufficient to provide weed control of species with protracted germination. To be effective, DFF must be absorbed by germinating weeds and translocated to the meristematic school tissues.

Seedlings originating below the DFF zone absorb DFF only through their shoots. Those originating in the DFF zone absorb DFF through their shoots and roots. Experiments have shown that shoot uptake is the major route of adsorption and uptake has been found to be greater for more susceptible species. Root uptake, although a less important route, is also greater in more susceptible species. Weed seedlings may be bleached on emergence and die rapidly. Seedlings of larger seeded species may have pigmented cotyledons but leaves subsequently develop symptoms. Cereal seeds germinate from below the DFF zone with the coleoptile protecting the young leaf as the shoot emerges. Any DFF absorbed moves towards the leaf tip rather than the meristem.

Post-emergence activity. Most material from a post-emergence application intercepted by plants will be retained by the leaves. DFF shows no useful phloem mobility, although some movement can occur, and DFF retained on or close to meristematic areas will therefore be important for post-emergence activity. Post-emergence applications of DFF hold interesting possibilities because only very low concentrations of DFF in meristematic areas are apparently necessary for activity. Formulation of herbicides can affect the activity of post-emergence applications by possibly affecting the retention of herbicide, its coverage of the plants and its penetration into the plants. Some aspects of DFF formulation have therefore been examined to determine opportunities for optimising biological activity.

MATERIALS AND METHODS

DFF was used as a suspension concentrate (S.C.) formulation, coded FR1078/3, containing 500 g/L DFF and as an emulsifiable concentrate (EC) coded FR1428/1, containing 150 g/L DFF. Both formulations were equivalent to commercially available formulations.

Laboratory trials were on plants grown in pots of John Innes No. 2 compost in glasshouses maintained at 25°C day and 15°C night temperatures with supplementary illumination for 14 hours per day. Spray applications were made to plants at the 2-3 leaf stage using a laboratory sprayer fitted with a SS8003E jet and applying a spray volume of 260 L/ha.

The ethoxylated alcohol surfactants Ethylan CD 103, 107 and 109, containing 2.9, 6.5 and 9.0 moles of ethylene oxide respectively, were obtained from Harcros Chemical Group.

The spread of 0.4 uL drops of solution applied by micrometer syringe to 'Parafilm' was determined by adding a water soluble dye to the solutions and measuring the areas of the dried deposits by image analysis.

The solubility of DFF in 1% solutions of surfactants was determined by HPLC analysis of filtered samples from the mixtures after equilibration.

RESULTS AND DISCUSSION

The effects of the addition of three alcohol ethoxylate surfactants with varied characteristics to sprays containing the S.C. formulation of DFF were examined. The three surfactants contained 2.9, 6.5 and 9.0 moles of ethylene oxide and all reduced the surface tension when added to water around 30 mN/M (Table 1).

All caused increased spreading of drops on a waxy surface with drops of solution containing surfactant CD 103 spreading the most. DFF solubility in 1% solutions of the surfactants was at least 90 times greater than in water, being highest in the solution of the surfactant CD 103.

Addition of all three surfactants to sprays of the S.C. formulation of DFF resulted in increased activity to levels similar to those obtained for acetone solutions of DFF (Table 1). Although addition of the surfactants increased the damage to barley it was not serious. Despite the differences in properties of the surfactants there were no differences in their effects on DFF activity. It may be supposed that the surfactants have varied effects on several processes including spray drop retention and spreading and penetration of DFF into shoot tissues, or, they may have similar effects on a major process such as DFF penetration. It has been reported that addition of surfactant to the S.C. formulation of DFF can considerably improve DFF penetration (4).

Table 1. Surfactant influence on DFF activity - Post-emergence

Surfactant	Mole ethylene oxide	Surface tension for 0.1% in water mN/m	Spread area for 0.1% in water mm^2	DFF solubility for 1% in water ug/mL	Activity for sprayed dose of 125 g/ha DFF as S.C. in water		
					Stellaria score¶	*Galium* % reduction green shoot tips	Barley % leaf area bleached
None	/	72	0.5	0.01	2.0	55	0.5
CD 103†	2.9	30	24	8.4	2.7	84	2
CD 107†	6.5	30	4	2.3	2.7	83	2
CD 109†	9.0	33	2	0.9	2.3	88	2
Acetone solution	/	/	/	100 mg/mL	3.0	75	10

† Ethylan CD : alcohol ethoxylate
¶ (5 = bleached + very stunted)
(0 = as control)

The S.C. formulation of DFF has been successfully developed and was used for the initial development of DFF in Australia. It has been commercialised for early post-emergence control of cruciferous weeds in lupins at does rates of 50-100 g/ha of DFF. Development of DFF for use in winter cereals in Australia evaluated mixtures of the S.C. formulation and MCPA or bromoxynil as ester E.C. formulations. Co-formulation of these components required that a non S.C. formulation of DFF be developed and an E.C. formulation was found to have good activity (Table 2). Co-formulation of DFF and MCPA ester in an E.C. formulation has been shown to improve activity relative to that of the tankmix (P. Buerger, pers. comm., 1987) possibly due to improved penetration. Use of this formulation type has allowed commercial levels of activity to be achieved with only 25 g/ha of DFF.

Table 2. Activity of DFF applied post-emergence
ED90 for weed species and ED10 for barley in g/ha

	Formulation		
	S.C. in water	E.C. in water	Acetone
Stellaria media	119	84	56
Galium aparine	1 055	117	368
Ipomoea purpurea	>500	64	82
Barley	>>500	≥500	250

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DE-511, A NEW LOW-RATE TRIAZOLOPYRIMIDINE SULFONANILIDE HERBICIDE FOR CONTROL OF BROAD-LEAVED WEEDS IN CEREALS AND MAIZE

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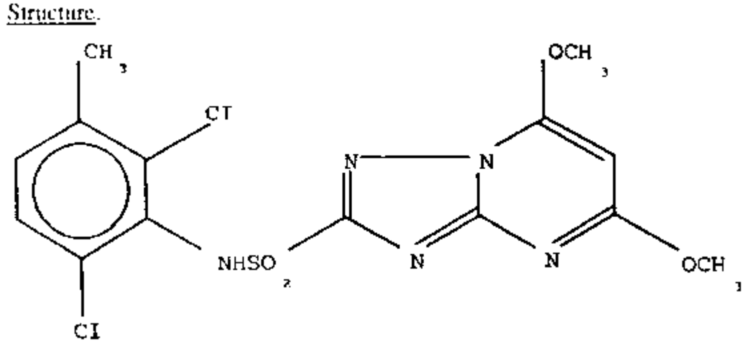
Summary. DE-511, N-(2,6-dichloro-*m*-tolyl)-5,7-dimethoxy[1,2,4]triazolo[1,5a]pyrimidine-2-sulfonamide (ISO proposed common name - metosulam) is a new selective herbicide for the control of broad-leaved weeds in cereals and maize. Typical application rates in cereals range from 5 to 15 g.a.i. ha^{-1} post-emergence and in maize from 20 to 30 g.a.i. ha^{-1} pre- or post-emergence. DE-511 is a representative of the chemical family triazolopyrimidine sulfonanilides and can be formulated in both aqueous and dry systems. Favourable results were obtained in toxicological and environmental studies. The latter studies suggest that no restrictions are required with regard to rotational crops.

INTRODUCTION

DE-511, N-(2,6-dichloro-*m*-tolyl)-5,7-dimethoxy[1,2,4]triazolo[1,5-a]pyrimidine-2-sulfonamide (ISO proposed common name - metosulam) is a novel low-rate herbicide discovered by DowElanco. This representative of a new generation of herbicide chemistry, the triazolopyrimidine sulfonanilides is being developed by DowElanco Europe and affiliated companies for post-emergence control of broad-leaved weeds in all cereal species and for both pre- and early post-emergence control of key broad-leaved weeds in maize. The triazolopyrimidine sulfonanilide chemistry allows a high degree of formulation flexibility, and DE-511 can be formulated in both liquid and dry systems. This paper will summarise the chemistry, toxicology, environmental fate in soil and water, fate in plants and mode of action of DE-511. The herbicidal efficacy and selectivity in cereals and maize, as well as the aspect of safety to rotational crops under European conditions is reviewed by Snel *et al.* (3).

CHEMICAL AND PHYSICAL PROPERTIES

Structure.



Proposed common name (ISO): metosulam

Chemical name:

(IUPAC):

N-(,6-dichloro-*m*-tolyl)-5,7-dimethoxy[1,2,4]triazolo[1,5-a]pyrimidine-2-sulfonamide.

(CA):

N-(2,6-dichloro-3-methylphenyl)-5,7-dimethoxy[1,2,4]triazolo[1,5-a]pyrimidine-2-sulfonamide

Molecular weight:		418.26
Melting point:		210-211·5C
Solubility in water (at 20C):		
distilled water	(pH 7.5)	200 mg L^{-1}
aqueous buffers	(pH 5.0)	100 mg L^{-1}
	(pH 7.0)	700 mg L^{-1}
	(pH 9.0)	5,600 mg L^{-1}
Dissociation constant:		$pK_a = 4.8$
n-Octanol/Water partition Coefficient at 20C :		
Aqueous phase	(distilled water)	log P_o/W = 0.9778
Vapour pressure:		4 x 10-13 Pa at 20°C

TOXICOLOGY

Acute mammalian toxicity.

- Acute Oral LD_{50}
  - Rat (Fischer 344) — >5,000 mg kg^{-1} BW
  - Mouse (CD - 1) — >5,000 mg kg^{-1} BW
- Acute Percutaneous LD_{50}
  - Rabbit (NZW) — >2,000 mg kg^{-1} BW
- Inhalation LC_{50} at **maximum attainable** concentration.
  - Rat (Fischer 344) — >1.9 mg L^{-1}

Primary irritation tests.

- Skin Irritation
  - Rabbit — Non-irritant
- Eye Irritation
  - Rabbit — Non-irritant

Skin sensitisation.

- Guinea pig — Non-sensitiser

Mutagenicity tests. Five mutagenicity tests systems *(in vitro/in vivo)* were used to evaluate DE-511. This molecule did not induce genotoxic changes and is thus deemed to be non-mutagenic.

Sub-chronic and chronic toxicity. Renal toxicity was evident in both short and long-term feeding studies, with the rat identified as the most sensitive species (2-year NOEL 5 mg/kg BW/day). No adverse effects were observed in reproductive toxicity studies. The data generated indicate that the potential human exposure associated with the proposed agricultural uses should not present a hazard.

Ecotoxicology. Results of extensive ecotoxicological studies indicate that DE-511 and its formulations should not present a hazard to wildlife and desirable soil organisms when applied in accordance to good agricultural practices.

ENVIRONMENTAL FATE IN SOIL AND WATER

Soil. Aerobic degradation studies conducted under laboratory conditions showed a half-life in soil with an average DT_{50} value of 6 days (range : <1 to11 days). Further experiments showed that the degradation of DE-511 is microbially mediated with very little degradation taking place under anaerobic conditions. Metabolite formation was observed 3 days after the initiation of the aerobic study. Under actual field conditions over two seasons, an average DT_{50} value of 20 days, depending on soil type, weather conditions and geography was demonstrated in six geographically well separated experiments. These trials on the dissipation of DE-511 in soil under field conditions were conducted in England and Germany in 1992 and 1990/91, respectively. Standard laboratory leaching studies (BBA, 1986) showed that under the extremely adverse environmental conditions prescribed in the protocol of these experiments, DE-511 possessed only a very limited mobility in all soil types with the exception of sandy soils.

Water. DE-511 is stable to hydrolysis at 25°C across the normal environmental pH-range (pH 5 to 9).

FATE IN PLANTS AND MODE OF ACTION

Plant metabolism. A plant metabolism study in wheat has been conducted using a ^{14}C labelled DE-511 formulation. The radiolabelled formulation was applied at growth stage ZD30 (beginning of stem elongation) at an application rate equivalent to 100 g a.i. ha^{-1}, viz at 7-10 times the rate to be recommended. Only approximately 1% of the total applied radioactivity was absorbed by the plants. Metabolism was not very extensive because the major component (>80% of the radioactivity present) in green plant tissue at all sampling times was the parent molecule. The total levels of parent and any metabolites at harvest were very low especially when the elevated application rate is taken into account, viz. 0.01 and 0.125% applied radioactivity in grain and straw, respectively, which expressed as DE-511 equivalents represents levels of 0.005 ppm and 0.05 ppm, respectively.

Residues in plants. When applied at rates ranging from 15 to 40 g a.i. ha^{-1} in a wide range of cereal species/varieties at growth stage ZD30-39, DE-511 residues could not be detected in grain (lowest validated limit of determination: 0.01 mg kg^{-1}). Residues of DE-511 in straw were occasionally above the lowest validated limit of determination (0.1 mg $kg^{-1)}$ but always <0.5 mg kg^{-1}. These extremely low residue levels in grain and straw combined with the favourable mammalian toxicity allow the conclusion that there is negligible risk to consumers of treated crops.

Mode of action. Gerwick *et al.* (2) presented physiological and biochemical evidence that triazolopyrimidine sulfonanilides act by inhibition of the first common enzyme to branched-chain amino acid synthesis, acetolactate synthase (ALS). Most of these tests were conducted with N-(2,6-dichlorophenyl)-5,7-dimethyl[1,2,4]triazolo[1,5-a] pyrimidine-2-sulfonamide, an analogue of DE-511. Concentrations as low as 0.006-0.010 ppm of this analogue effectively caused total inhibition of growth in soybean suspension cultures. The herbicidal effect could be completely reversed in the presence of valine, leucine and isoleucine. *In vitro* studies with isolated ALS from susceptible and tolerant plant species showed that the concentrations at which the analogue of DE-511 gave 50% inhibition of the enzyme activity (I_{50}) fall within a narrow range (0.11 to 0.45 M), whilst the GR_{50} (50% growth inhibition) following foliar applications showed a spread of 9-500 mg L^{-1}. DE-511 produced an I_{50} value of 0.0012 M on barley ALS, which presents a significant advance in enzyme inhibition over the earlier analogue described above.

CONCLUSIONS AND SUMMARY

DE-511 (ISO proposed common name: metosulam) is a representative of a new generation of herbicide chemistry, the triazolopyrimidine sulfonanilides. DE-511 has been shown to be safe to all winter cereal species. The optimum time of application in winter cereals is post-emergence in the spring at a rate of 10-15 g a.i. ha^{-1}. These rates present no safety problems in key rotational broad-leaved crops such as oil seed rape and sugar beet. (Snel *et al.*, 3). In view of its flat dose response curves seen for the key cereal broad-leaved weeds, the optimal application rate is 10 g a.i. ha^{-1} under Northern European conditions.

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CHARACTERISING LOW VOLUME SPRAY DEPOSITS USING ARTIFICIAL TARGETS

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Summary. Using undescribed twin fluid nozzles, quantitative fluorometric studies were used to determine relative retention of sprays as captured by artificial targets. When considering the whole target, changes in boom speed and nozzle orientation had little effect on retention. A uniform static spray distribution for twin fluid nozzles was achieved using 25 L air/min/nozzle, a boom height of 50 cm and nozzles orientated 22.5° above the horizontal. Within targets however, the relative capture by horizontal and vertical collectors was dependent on nozzle orientation and boom height. Using twin fluid nozzles it was shown that application of an aqueous-based spray at 20 L/ha and 10 km/hr is a practical method of applying low volumes of spray solution.

INTRODUCTION

The inefficiencies of using hydraulic nozzles in boom spraying operations (2) results in a limit being reached where volumes can no longer be reduced without detrimental environmental and ecological effects (3, 4). Unevenness in the spray pattern and the high ground speeds required to accomplish low application rates renders conventional low volume systems unreliable. More accurate means of applying herbicides at ultra low volumes (<10 L/ha) were investigated by McWhorter (9) with the development of twin fluid spray nozzles for the application of oil-soluble herbicides in paraffinic oils. These nozzles enabled adequate distribution of herbicide to give season-long control of seedling and rhizomatous johnsongrass (*Sorghum halepense* (L.)) (1).

The major advantage of twin fluid nozzles is their ability to atomise low flow rates of liquid without being prone to nozzle blockages. While herbicide dose rates can be reduced, the expense of adjuvants such as paraffinic oils and emulsifiers raise the operating cost of twin fluid nozzle ULV systems. For this reason, a very low volume aqueous system, ie. 10-40 L/ha, is being investigated which substantially reduces the cost of herbicide application.

The use of artificial targets help define the optimal parameters of spraying (7). In these trials stainless steel rods were used to assess the influence of boom height, sprayer speed, nozzle orientation and target angle on spray retention as measured by quantitative fluorometry (11).

METHODS

<u>Patternator testing.</u> A patternator comprising 25 mm channels was used to establish optimal spraying parameters for a pair of modified *Lurmark* AN 5.0 deflector nozzle tips. Spray pattern uniformity was calculated as coefficients of variation (c.v.%) over 5 boom heights (20, 30, 40, 50, 60 cm), 5 flow rates (20, 22.5, 25, 27.5, 30 L of air/min/nozzle) and two nozzle orientations (horizontal (0°) or directed 45° above the horizontal (+45°)). This equates to spray sheets being 25° and 70° above the vertical respectively. In all cases, the spray sheet was offset 10° to the boom. Using a sprayer speed of 10 km/hr, a nozzle spacing of 50 cm and a liquid flow rate of 166 mL/min/nozzle, application rate corresponded to 20 L/ha. The spray solution used for these

studies contained 0.1% (v/v) nonylphenol ethyloxylate wetting agent (*Agral 600*, Imperial Chemical Industries) in tap water (28 ppm $CaCO_3$).

Spray retention studies.

Targets for spray deposition. Artificial targets were constructed from stainless steel rods 5 mm in diameter and 110 mm in length, 100 mm of which was exposed to spraying. The rods were fitted into a rectangular perspex block 160x75x20 mm, by drilling holes at 7 angles (0°, 15°, 30°, 45°, 60°, 75°, 90°) around the perimeter of the block. In these experiments, 4 rod angles (0°, 30°, 60°, 90°) were used. Six targets were placed on a three row by two column grid pattern on the spraying platform for each spraying event.

Spray deposit determination. For spray cabinet studies, the spray solution also contained 0.5% (w/v) *Fluorescein LT* (Harcros Colours). A pair of modified *Lurmark* AN 5.0 deflector nozzle tips were spaced 50 cm apart and offset 10° to the boom. Unless otherwise stated, spraying was carried out using nozzles oriented horizontally (spray sheet angle of 25° above the vertical), with a liquid flow of 166 mL/min/nozzle and 25 L of air/min/nozzle at 10 km/hr. This equated to an application rate of 20 L/ha. Boom height was adjusted to 50 cm above the target canopy for nozzle angle changes. Spray deposit on the targets were quantified by measurement of a fluorescent tracer (10).

Separate experiments investigated the relationship of retention to nozzle orientation, boom speed, boom height and the interaction of nozzle orientation and boom height. The first experiment investigated the effect of three nozzle orientations (0°, +22.5° or +45°, spray sheet angles of 25°, 47.5° and 70° respectively) on retention, each orientation event being replicated three times. Secondly, relative retention at eight boom speeds (9, 10, 11, 12, 13, 14, 15, 16 km/hr) with nozzles oriented at 0° was investigated. Thirdly, relative retention was quantified at three boom heights (30, 40, 50 cm) and three nozzle orientations (0°, +22.5° or +45°).

RESULTS

Patternator testing. Table 1 gives the coefficient of variation of spray distribution for a pair of twin fluid nozzles when oriented 0° and 45°. A range of air flow rates were tested. A boom height of 50 cm and an air flow of 25 L air/min/nozzle gave the most uniform spray pattern for both nozzle orientations. These operating parameters were then used throughout the remainder of this work. The data indicates that a lowering of air flow by 2.5 or 5 L air/min/nozzle and the raising or lowering the boom by 10 cm, does not greatly affect uniformity. Nozzles orientated 0° were generally more uniform than those orientated +45°. Optimal boom height was between 40 and 60 cm depending on air volume.

Retention studies. There was no significant changes to total spray retention when nozzle angle was altered (Table 2). However, compared with 0° and 45° nozzle orientations, up to 35% more spray was retained by the more vertical targets (60° and 90°) when nozzles were orientated +22.5°. The data also shows that for the three nozzle orientations tested spray retention significantly ($P=0.05$) increased with decreasing target angle, ie. the more horizontal the target the more spray was retained. For nozzle orientation, boom height and speed studies, retention dramatically decreased with increasing target angle: 0°>30°>60°>90° (Tables 2, 3 and 4). Retention of spray was independent of boom speed and nozzle orientation (Table 3), but dependant on boom height (Table 4).

Table 1. Coefficients of variation (%) of lateral spray distribution for changes in nozzle orientation, boom height and air flow

Boom Height	Air flow (L air/min/nozzle) and nozzle orientation (°)									
	20		22.5		25		27.5		30	
	0°	+45°	0°	+45°	0°	+45°	0°	+45°	0°	+45°
20 cm	28.2	33.2	29.1	32.5	29.8	33.6	34.3	35.3	39.8	38.6
30 cm	13.8	15.3	9.1	13.7	10.3	14.0	14.2	16.0	17.7	21.0
40 cm	9.1	6.2	10.1	7.4	10.3	7.5	14.2	9.2	9.9	11.5
50 cm	11.4	7.8	9.7	8.0	8.5	6.1	9.6	6.8	10.1	9.0
60 cm	8.9	8.8	7.4	5.9	10.4	7.3	13.9	10.1	15.5	11.4

Table 2. Spray solution retained (mL/sq mm) by artificial targets at various nozzle orientations (l.s.d. P=0.05)

Target angle	Nozzle orientation		
	0°	22.5°	45°
0°	0.554	0.553	0.560
30°	0.447	0.445	0.420
60°	0.329	0.376	0.344
90°	0.200	0.234	0.173
l.s.d. (angle *x* orientation) = 0.064			
Total	0.384	0.402	0.374
l.s.d. (angle) = 0.033			

The data in Table 4 shows that there were no significant (P=0.05) changes in overall collection by targets if the nozzle orientation was varied from 0° to 45°. However, there were significant changes for some of the interacting parameters. For example, by lowering the boom height from 50 to 40 to 30 cm retention was significantly increased. The data also shows that as target angle decreases from the vertical to 30° retention is significantly increased. Further, when the nozzles were orientated horizontally, the 0° and 30° targets collected as much as 50% less spray at a boom height of 40 cm than at either 30 or 50 cm. However, as nozzle angle was increased the quantity of spray solution retained on horizontal targets decreased by as much as 15% as the boom was raised from 30 to 40 to 50 cm.

It can be concluded that the large variations in spray retention measured reflect the interactions between target orientation, spray sheet angle and boom height. Optimum retention was obtained on a horizontal target using horizontal nozzles. the lowest collection (29% of the highest), was on a vertical target with a 22.5° nozzle angle.

Table 3. Spray solution retained (L/sq mm) by artificial targets at various boom speeds (l.s.d. P=0.05)

Target angle	Speed (km/hr)								
	9	10	11	12	13	14	15	16	Mean
0°	1.113	1.245	1.158	1.147	1.112	1.035	1.262	1.145	1.155
30°	1.021	.988	1.054	.908	1.002	1.116	1.255	1.061	1.049
60°	.823	.710	.906	.664	.966	.624	.848	.605	.786
90°	.418	.352	.614	.797	.731	.545	.520	.534	.564
Mean speed	.846	.824	.933	.879	.953	.830	.971	.836	.884

l.s.d. (speed) = 0.313
l.s.d. (leaf *x* speed) = 0.316

Table 4. Interaction of nozzle orientation and boom height on retention (L/sq mm) of spray solution by artificial targets (l.s.d. P=0.05).

Target angle height (cm)	Nozzle orientation									Mean
	0°			22.5°			45°			
	50	40	30	50	40	30	50	40	30	
0°	.661	.489	.718	.566	.584	.650	.533	.596	.644	.604
30°	.614	.467	.610	.500	.525	.487	.500	.508	.586	.533
60°	.434	.353	.464	.425	.496	.491	.370	.459	.467	.440
90°	.242	.244	.363	.207	.257	.340	.290	.210	.442	.288
Mean nozzle		.472			.461			.467		
Mean height	.488	.388	.539	.424	.465	.492	.423	.443	.535	.466

l.s.d.. (leaf *x* angle *x* height) = 0.123
l.s.d.. = (angle *x* height) = 0.109

DISCUSSION

Artificial targets are useful in identifying sources of variation in deposits over a given area, but are not reliable substitutes for estimating retention on leaves (5, 6). Of the possible artificial targets available, rods and cylinders are preferred as they are the most efficient collectors (8).

The patternating studies presented demonstrate the complex interactions that boom height, nozzle orientation and air flow rates have on the uniformity of the spray pattern. Interestingly, minor adjustments to these parameters did not appreciably alter the uniformity of retention, but would presumably have influenced drop diameter, velocity and trajectory. The work of Elliott *et al.* (5) indicates that any increase in retention, eg. by lowering boom height or reducing air flow rate, is at the expense of uniformity in spray distribution.

In contrast to the studies of Richardson (11), where spray retention of flat fan nozzles was increased by more than 200% when nozzles were directed forward 45°, overall retention of spray deposits in this study were not influenced by nozzle orientation. However, retention on the vertical targets was significantly increased (50-64%) when the boom was lowered from 50 to 40 to 30 cm. The reason for the lower increase in retention compared with Richardson (11) could be the nozzles (twin fluid *vs.* flat fan), the case of artificial *vs.* natural targets or sprayer speed (6 *vs.* 10 km/hr). Retention by horizontal target rods was generally independent of nozzle orientation. Vertical targets typically retained less than half the amount of spray of horizontal rods. This indicates that the relative proportion of spray intercepted by targets is related to their angle (0°>30°>60°>90°) (12). The data showed that a low c.v.(%) on a patternator does not necessarily equate to maximum retention.

From the results it can be concluded that boom height and target orientation are the two most important parameters affecting increased retention. A boom height of 30 cm when spraying vertical targets can be expected to increase spray retention by up to 60%. However, collection on horizontal targets is unlikely to be greatly affected.

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EVALUATION OF SURFACTANTS FOR INCREASING THE EFFICACY OF TRICLOPYR ON GORSE IN HAWAII

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Summary. Field trials were conducted to evaluate different commercial surfactants for their ability to increase the efficacy of triclopyr on gorse (*Ulex europaeus*) in the Humuula district, elevation ca 1800 m, on the island of Hawaii. Silwet L-77® (polyalkyleneoxide modified polydimethylsiloxane, hereafter L-77) increased the efficacy of 1.6 kg a.e./ha triclopyr (butoxyethyl ester) over an unlabelled critrus oil emulsion (hereafter CIT) but not significantly over two other surfactants. L-77 did increase the efficacy of the triethylamine salt of triclopyr at 1.0 kg/ha over the other surfactants used, especially in the mortality rates of treated gorse plants, 80% kill in contrast to 0-10% for other surfactant treatments. These results suggested that triclopyr amine with L-77 would be more effective in controlling gorse than triclopyr ester with any of the surfactants evaluated with it.

INTRODUCTION

Gorse infests 14,000 ha between 1230 m and 2155 m elevation at two location in Hawaii, Humuula on the northern slope of Mauna Kea on the island of Hawaii, and Olinda on the western slope of Haleakala on the island of Maui (10). Roughly 25% of the gorse-infested area is densely infested (10). Concern over the gorse problem led to the creation of an interagency Hawaii Steering Committee on Gorse Control to coordinate control efforts and secure funding for research. Part of the control effort centers on chemical control for interim suppression of gorse while research on biocontrol and grazing management are conducted. Until recently picloram had been the herbicide of choice for controlling gorse. However new and stringent regulations make picloram use impractical. For example broadcast spraying is not allowed. In the United States, triclopyr cannot be applied at rates in excess of 1.12 kg a.e./ha in pastures although up to 3.36 kg/ha may be applied in forests and non-cropland. Triclopyr at 1.12 kg/ha only provides marginal efficacy with conventional surfactants (8). Therefore surfactants that can increase the efficacy of triclopyr on gorse are a critical need. Balneaves (2) and others (3, 6, 7, 11) reported that L-77 was very effective in improving the efficacy of metsulfuron and glyphosate on gorse. Motooka *et al.* (8) reported that L-77 increased the efficacy of metsulfuron and of triclopyr (triethylamine salt) more than a commonly used nonionic surfactant Ultramar NI® (nonylphenoxypolyethoxyethanol, hereafter NI) on gorse in Hawaii. This report covers further evaluations of surfactants for increasing the efficacy of triclopyr on gorse.

METHODS

Two trials were conducted on pastures at ca 1800 m at Humuula, on the northern slope of Mauna Kea, island of Hawaii. In both trials, plots consisted of individual shrubs 1 m to 1.5 m tall, replicated 10 times and completely randomized. Treatments were applied with a CO_2-powered sprayer with a four-nozzle boom with SS8003 LP nozzle tips. Pressure was set at 207 kPa. The spray-volume rate was 320 L/ha. Evaluations were made by visual estimation of the percentage of necrotic canopy and on the percentage of plants killed.

Trial 1. The surfactants evaluated with triclopyr ester at 1.8 kg/ha were L-77, NI, Activate 3® (dimethylpolysiloxane, alkyloxypolyethoxy ethanol, and propylene glycol, hereafter A3), and CIT. Evaluations were made at 8 months after treatment (MAT).

Trial 2. The surfactants evaluated with 1 kg/ha of triclopyr amine were L-77, A3, Herbimax (petroleum solvents and esters of omega hydroxypolyoxyethylene, hereafter HBX), LI 700® (phosphatidylcholine and methylacetic acid, hereafter LI), NI, NI plus 5 ppm 2,4-D (dimethylamine salt), and NI plus 0.5% $(NH_4)_2SO_4$ (w/v). The use of 2,4-D as an adjuvant was attempted on the rationale that its ability to elongate cells would disrupt the integrity of the cuticle. The ammonium ion increases uptake, translocation or both of some herbicides (5, 9). Evaluations were made at 6 MAT.

RESULTS AND DISCUSSION

Trial 1. The L-77 treatment was significantly superior to the CIT treatment but all other differences between means were non-significant. All treatments produced severe necrosis in gorse but by 8 MAT new shoots were emerging on the branches of most plants. Very few of the plants were killed. The highest mortality rate, in the L-77 treatment was only 20%. Some data reported by Burrill *et al.* (4) and Motooka *et al.* (8) suggested improvement in efficacy of triclopyr ester on gorse with L-77. The severe injury induced by treatments suggested that a repeat application similar to the "double kill" method of Balneaves (1) should improve the mortality rate.

Table 1. Response of gorse to triclopyr ester with different surfactants eight months after treatment

Surfactant	Injury rating[a,b] (%)	Kill (%)
0.5% NI	87[cd]	0
0.2% L-77	93[c]	20
0.5% A3	80[cd]	10
0.5% CIT	76[d]	0

[a] Visual estimate of percentage of canopy killed.

[b] Means followed by the same letters are not significantly different at $P = 0.05$ by Duncan's Multiple Range Test.

Trial 2. The best amine treatment was that with L-77 in which both the injury rating and the kill rate of 80% were superior to all other treatments. There was no difference in injury ratings and kill rates between the rest of the treatments. The kill rates for those treatments were only 0-10%. Kill by triclopyr ester with L-77 in trial 1 was only 20% in constrast to the 80% kill of the amine formulation with L-77 in trial 2 despite the fact that the triclopyr ester was applied at a higher rate. Burrill *et al.* (4) reported high efficacy ratings in one trial at 12 MAT by several herbicides including triclopyr amine and ester regardless of whether surfactants were used or of what kind of surfactants were used. However, their application procedures suggested that the rates of herbicide they used, which were not reported, were probably higher than those used in these trials.

Table 2. Response of gorse to triclopyr amine with different surfactants six months after treatment

Surfactant	Injury rating[a,b] %	Kill (%)
0.5% NI	54[d]	0
0.5% NI + 5ppm 2,4-D	70[d]	10
0.5% NI + 0.5% $(NH_4)_2SO_4$	74[d]	10
0.2% L-77	99[c]	80
0.5% A3	58[d]	0
0.5% HBX	60[d]	0
0.5% LI	66[d]	0

[a] Visual estimate of percentage of canopy killed.
[b] Means followed by the same letters are not significantly different at $P = 0.05$ by Duncan's Multiple Range Test.

The mortality rate reported here suggests that L-77 is superior to other tested surfactants and especially so with triclopyr amine. Thus triclopyr amine with L-77 should provide greater efficacy than triclopyr ester with L-77 on gorse.

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ADJUVANTS IMPROVE CONTROL OF WARM ZONE GRASSES WITH SULFONYLUREA HERBICIDES IN MAIZE

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Summary. Several pot experiments evaluated the effects of growth stage and of various adjuvants on the efficacy of rimsulfuron, nicosulfuron and primisulfuron on warm zone grass weeds. Two field trials in maize crops also evaluated the best adjuvants with rimsulfuron and primisulfuron under temperate conditions in New Zealand. In pot experiments rimsulfuron and nicosulfuron had a similar level of activity and were more active on grass wees than was primisulfuron. Of the grass weeds smooth witchgrass, *Panicum dichotomiflorum*, was more readily controlled than whorled pigeon grass, *Setaria verticillata* and summer grass, *Digitaria sanguinalis*. The most successful application time was when the grasses had two to four leaves as the level of control decreased once they began to tiller. The adjuvants Pulse, Ethokem and Citowett were more effective than crop oil and X-45. These results were reflected in the field trials where the use of an adjuvant was essential to maximise phytotoxicity of all three herbicides. Rimsulfuron gave effective control of a range of grass weeds while primisulfuron was more effective on broadleaf weeds.

INTRODUCTION

The sulfonylurea herbicides are being developed for a variety of uses. Various members of this group are registered for use in cereals, rice, soy beans, oilseed rape as well as for total vegetation control. Others are being developed for use in several other crops and pastures, as well as for aquatic weed control (1,2,3,6). The broad spectrum and reliability of weed control, the low dose rate and the favourable toxicological profiles of these compounds have contributed to the rapid rise in the use of this group of herbicides.

Over the last few years several sulfonylurea compounds have been evaluated for weed control in maize. Nicosulfuron, rimsulfuron and primisulfuron have all shown promise for control of certain troublesome perennial grasses at rates similar to those required for annual grass weeds, as well as providing good control or suppression of many broad-leaved weeds (5, 7, 11). Our early developmental work with these three herbicides in the field indicated that non of them provided adequate control of summer grass, one of the major annual grass weeds of the maize growing regions in New Zealand (12). Oil and surfactant adjuvants have been reported to enhance the activity of many post-emergence herbicides including sulfonylureas, and maintain their effectiveness across varied environments (4,8,9,10). The present study, comprising both pot and field experiments, investigated whether certain adjuvants and additives can enhance the phytotoxicity of the three sulfonylurea herbicides on the major warm zone grass weeds of maize fields in New Zealand.

METHODS

Pot experiments. Four experiments were conducted on grass weeds grown outdoors in pots over a two year period. The grasses were established by potting out soils known to contain a natural seed bank of the desired species and then removing unwanted plants by hand. In the first two experiments, initiated 8 January and 1 February 1990, three species were grown, viz. summer grass, smooth witchgrass and whorled pigeon grass, while the second two experiments, laid down on 21 December 1990 and 3 January 1991, included only summer grass and smooth witchgrass. In all experiments the herbicides were applied at three rates to each of three growth stages, 2-leaf, 4-leaf and 6-leaf, with a variety of adjuvants. The herbicides used were rimsulfuron, nicosulfuron and primisulfuron. Rimsulfuron was applied at 10, 15 and 20 g/ha at the 2 and 4-leaf stages and at 15, 20 and 30 g/ha at the 6-leaf stage while nicosulfuron were used at 30, 45 and 60 g/ha at the 2 and 4-leaf stages and at 45, 60 and 80 g/ha at the 6-leaf stage. The adjuvants used were an emulsifiable vegetable oil (Codacide oil), an organo-silicone co-polymer surfactant silwet-M (Pulse), a white emulsifiable crop oil (BP crop oil), a cationic wetting agent polyethanoxyl alkyl amine (Ethokem) and the non-ionic surfactants, alkylarylpolyglycol ether (Citowett) and alkylarylpolyether alcohol (Triton X-45) (see Table 1 for rates). In all experiments the herbicide/adjuvant combinations were premixed according to label instructions and applied with a moving belt CO_2 powered sprayer, fitted with an 8003 even spray nozzle, delivering 300 L/ha at 200 kPa. For the duration of each experiment pots were watered every 2-3 days as required to maintain the soil between 70 and 90% of field capacity. Day temperatures were between 20 and 25°C, with night temperatures sometimes dropping to 10°C. Herbicide response was evaluated by regular visual damage assessments and by counting the surviving plants 4-5 weeks after spraying.

Table 1. Effect of adjuvants on the activity of three sulfonylurea herbicides on summer grass (DIGSA) and smooth witchgrass (PANDI) at the 2-leaf stage

Adjuvant	Rate	% Control					
		Nicosulfuron[a]		Rimsulfuron		Primisulfuron	
		DIGSA	PANDI	DIGSA	PANDI	DIGSA	PANDI
-	-	52	65	50	60	48	75
Pulse	0.2% v/v	63	92	85	100	60	95
Citowett	0.2% v/v	50	85	82	100	53	97
Triton X-45	0.2% v/v	48	90	63	95	52	95
Ethokem	1 L/ha	100	100	95	100	55	100
crop oil	2 L/ha	48	95	80	95	57	100
Codacide oil	1 L/ha	50	97	95	98	57	95
l.s.d. (P=0.05)		12.8	8.5	9.2	6.3	12.8	4.6

[a] Nicosulfuron and primisulfuron applied at 30 g/ha, rimsulfuron at 10 g/ha.

Field experiments. Two field trials were conducted in maize, *Zea mays*, on a Horotiu sandy loam soil with 61% sand, 16% clay, 5.8% organic C and a pH of 5.6. The maize cv. Pioneer 3475 was planted on 22 October 1991 and 20 October 1992 with a Nodet Gougis precision seeder at 88,000 seeds/ha and 75 cm row spacing. For Trial 1 (Table 2), alachlor was applied 2 days after planting; all other treatments were applied 35 days after planting when maize plants had 4-5 leaves, grass weeds 1-6 leaves and broadleaf weeds 4-12 leaves. For the post-emergence treatments the weather was sunny and 19°C and 3 mm of rain fell within 24 hrs of application. For Trial 2 (Table 3), alachlor was applied 7 days after planting; all other treatments were applied 29 days after planting, when maize plants had 3-4 leaves, grass weeds 3-5 leaves and broadleaf weeds 4-6 leaves. Conditions for the post-emergence treatments were overcast and 17°C and 4.3 mm of rain fell within 24 hrs of treatment. Both trials were of a randomised block design with four replicates and individual plots of 10x3 m. All treatments were applied with a CO_2 powered precision sprayer in 200 L water/ha at 210 kPa. Visual assessments for weed control and crop damage were made at regular intervals after treatment. Weed dry matter production was determined 6-8 weeks after planting by harvesting duplicate 0.5 m^2 quadrats from each plot and dissecting into grass and broadleaf weeds before drying. Grain yields for Trial 1 were determined by harvesting 25 cobs from each of the two central rows of each plot. The cobs were shelled, weighed and the moisture content of the grain measured. Grain yields are adjusted to 14% moisture levels.

Table 2. Effect of treatments on grass and broadleaf weeds in maize, Field Experiment 1

Adjuvant	Rate	Adjuvant	Weed assessment				Crop yield (t/ha)
			% Control		Dry matter (kg/ha)		
			Grass 18.12.91	Broadleaf 18.12.91	Grass 30.12.92	Broadleaf 30.1.92	5.5.92
rimsulfuron	5	-	27.5	32.5	206 b	1316 a	6.23
rimsulfuron	10	-	42.5	40.0	35 c	1505 a	7.56
rimsulfuron	5	crop oil 2 L/ha	67.5	47.5	272 b	1597 a	6.05
rimsulfuron	5	Ethokem 3 L/ha	42.5	63.8	76 bc	1186 a	8.13
rimsulfuron	5	Pulse 0.2%	40.0	63.8	118 b	1612 a	7.13
rimsulfuron	5	Citowett 0.2%	27.5	57.5	118 b	1507 a	6.89
primisulfuron	30	-	27.5	76.3	1058 a	219 b	7.72
primisulfuron	30	crop oil 2 L/ha	55.0	86.3	701 a	149 b	7.82
primisulfuron	30	Ethokem 3 L/ha	42.5	90.0	310 a	297 b	8.75
primisulfuron	30	Pulse 0.2%	17.5	83.8	578 a	21 b	8.49
primisulfuron	30	Citowett 0.2%	96.3	85.0	866 a	150 b	8.24
alachlor	3500	-		60.0	1 c	2451 a	7.70
l.s.d. (P=0.05)			20.0	17.1	-*	-*	2.43

* Analysis performed on log transformed data, numbers followed by different letters are significantly different at the 5% level using l.s.d. test.

Table 3. Effect of treatments on grass and broadleaf weeds in maize. Field Experiment 2

Adjuvant	Rate	Adjuvant	Weed assessment			
			% Control		Dry matter (kg/ha)	
			Grass 18.12.91	Broadleaf 18.12.91	Grass 30.12.92	Broadleaf 30.1.92
rimsulfuron	10	-	47.5	58.8	481 abc	752 ab
rimsulfuron	10	Ethokem 3 L/ha	81.3	61.3	102 d	326 bc
rimsulfuron	10	Pulse 0.2%	81.3	65.0	166 bcd	768 ab
rimsulfuron	10	Citowett 0.2%	77.5	75.0	307 bcd	328 bc
primisulfuron	30	-	48.8	58.8	501 ab	684 b
primisulfuron	30	Ethokem 3 L/ha	65.0	98.8	1191 a	110 c
primisulfuron	30	Pulse 0.2%	70.0	98.8	907 a	227 bc
primisulfuron	30	-	95.0	80.0	21 e	841 ab
alachlor	3500	-	0	0	106 cd	3378 a
untreated	-					
l.s.d. (P=0.05)			12.9	19.4	-*	-*

* Analysis performed on log transformed data, numbers followed by different letters are significantly different at the 5% level using l.s.d. test.

RESULTS AND DISCUSSION

Pot experiments. The initial experiments with pot grown grass weeds showed that the activity of all three sulfonylurea herbicides was enhanced by the use of certain adjuvants. The results presented in Table 1, from the third experiment, are typical of those obtained from all four experiments. Of the three grasses used in these experiments smooth witchgrass was most susceptible, with all three herbicides achieving good control at the 2-leaf stage when used with an adjuvant. However, at the 4 and 6-leaf stages, smooth witchgrass proved more difficult to control, with only Ethokem and Codacide oil providing consistently good results. Control of summer grass and whorled pigeon grass was more difficult. Nicosulfuron and rimsulfuron, when used with Ethokem, were effective at all growth stages on both grasses. Primisulfuron was less dependent on the use of adjuvants but had very little effect on summer grass after the 2-leaf stage. On whorled pigeon grass primisulfuron was more effective on the larger plants but maximum control was still only 50-70% with or without adjuvants. The effect of all three herbicides was to stop plant growth for a period of about two weeks following treatment. After this time the plant either regrew, often from new basal shoots, or died. This high level of regrowth occurred in the absence of any competition in the pots whereas in the field significant competition could be expected from both the crop and other weeds.

Field experiments. In the first field experiment wed emergence was very irregular which made correct timing of the post-emergence treatments difficult. This was reflected in the high variance of the dry matter production and consequently large l.s.d. values (Table 2). However, there were significant differences in the initial activity resulting from the use of adjuvants, in particular Ethokem. There were also differences in the spectrum of grasses present after treatment. When used alone or with crop oil, rimsulfuron failed to control both summer grass and smooth witchgrass but when used with either Pulse, Citowett or Ethokem, only summer grass remained. Primisulfuron failed to control most grass weeds except when used with either Pulse or Ethokem which helped to control smooth witchgrass. It was also more effective on broadleaf weeds. All treatments were well tolerated by the maize crop with no visual injury apparent at any stage and grain yields were not significantly different in any treatment from that of the standard alachlor treatment.

In Trial 2 the post-emergence treatments were applied earlier to weeds that were more uniform in size and the rate of rimsulfuron was increased to achieve better control of broadleaf weeds (Table 3). Rimsulfuron was more effective on broadleaf weeds, especially when used with either Ethokem or Citowett, but this also allowed more grasses to grow and in some treatments grass weed control was inadequate. More effective control of the broadleaf weeds (especially atrazine resistant fat hen, *Chenopodium album*) by primisulfuron when used with Ethokem also increased the amount of grass weeds in that treatment even though smooth witchgrass was controlled by this combination.

The results of both the pot and field experiments show that adjuvants can be used to improve the efficacy of sulfonylurea herbicides on some grass weeds. It may also be possible to achieve satisfactory control of grass weeds at an advanced growth stage by the use of an adjuvant. Overall, Ethokem provided the most consistent improvement to the efficacy of these three herbicides, although the other adjuvants proved equally effective in some cases.

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MULTIPURPOSE AGRIMAX ADJUVANT SYSTEM

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Summary. Agrimax™ 3, 4, and 5 are proprietary multipurpose adjuvant compositions for pesticide formulations microemulsified as homogeneous, thermodynamically stable systems dilutable at all concentrations without separation. These formulations have imparted rainfastness and enhanced biological activity with several herbicides on many broad leaf and grass weed species when used as tank mix additives at 0.1-0.25% v/v.

INTRODUCTION

Some of the benefits derived from the proper use of adjuvants are enhanced biological activities resulting in a reduction in total use while maintaining efficacy, increased rainfastness, improved penetration, better wetting and spreading, and protection against UV radiation for the active ingredients. Agrimax™ adjuvant systems show many of these benefits. These adjuvants are based on N-alkylpyrrolidones and possess excellent physical profiles such as low surface tension, low contact angle, and low wetting time. Recent studies also showed that some pyrrolidones increase cuticular penetration and enhance translocation (1).

Stability. Agrimax™ 3 and 5 are water based optimized proprietary compositions. At appropriate dilutions, the particle size distribution was centered around 200-300 A°, well within the microdispersion range. Agrimax™ 4 is formulated in hydrocarbon and also contains water insoluble polymers. Dilution with water to 10%, 2%, 1% and 0.1% produced stable emulsions without separation even for weeks. The droplet size of the emulsion was <2 µm.

Surface properties. Table 1 summarizes the surface properties of Agrimax™ 3 and 5 in aqueous solutions as a function of dilution. Agrimax™ 5 has similar properties. If droplet dry-down is considered, assuming a reasonable estimate of 50% evaporation during flight, the effective values for the surface properties for Agrimax™ 3 are: instantaneous wetting time, surface tension of <28 dynes/cm, and contact angle of approximately 46 degrees. The effective values at 0.5% dilution for Agrimax™ 5 are 8 s wetting time, surface tension of <29 dynes/cm, and contact angle of approximately 46 degrees.

Ease of emulsification of actives. In the concentrated form Agrimax™ systems can solubilize a variety of active ingredients, especially those containing aromatic (benzenoid) compounds, carbamates, and hydrophobic esters at concentrations as high as 30%. Such systems are believed to be microemulsion/emulsion concentrates. On dilution in water these concentrates produced very stable emulsions with submicron droplet size, with unchanged particle size distribution even after standing for 2 weeks.

METHODS

Rainfastness evaluations. Commercial formulations of pendimethalin (as Prowl®) phosphonomethylglycine isopropylamine salt (as (Rodeo®), and carbaryl (as Sevin®) were diluted to end use concentrations and the appropriate Agrimax™ system added at 0.125-0.05% of final dilution. An aliquot (0.1-0.5 g) was applied to a glass/parafilm plate uniformly as a

2.5-7.5 cm square patch. After a dry film was obtained, a fine spray of water was applied to simulate 0.5-2.0 cm of rain wash-off. The washings were collected in a waste jar. The remaining washed patch was quantitatively extracted. The ethanol was analyzed by UV spectral analysis in the case of Prowl® and Sevin® and by potentiometric titration for Rodeo®.

Biological evaluations. The same rates of Agrimax® system adjuvants were added to commercial samples of paraquat (Gramoxone®) and glyphosate (Roundup®) and sprayed onto weeds under two year old citrus trees at Lake Alfred, Florida. The major grass weed was Bahia grass (*Paspalum notatum*) and the major broad-leaf weed species included *Heterotheca subaxillaris*, white eye (*Richardia brasiliensis*), Mexican tea (*Chenopodium ambrosiodes*), fat hen (*Chenopodium album*), green amaranth (*Amaranthus viridis*), cobbler's pegs (*Bidens pilosa*) and spiny head sida (*Sida acuta*).

The plots were visually rated 3, 7, 21, 42 and 63 days after spraying.

RESULTS

Table 1. Surface properties of aqueous Agrimax™ 3 and 5

% Dilution	Concentration ratio	Surface tension (dynes/cm)	Contact angle[a] (degree)	Wetting time (S)
	Agrimax™ 3			
1/100	1.0	26.5 ± 0.1	41.6 ± 5	0
1/133	0.75	26.1 ± 0.1	42.6 ± 4	0
1/200	0.50	27.9 ± 0.1	46.2 ± 7	0
1/400	0.25	29.7 ± 0.08	55.6 ± 7	8.0 ± 1
1/666	0.15	30.6 ± 0.08	65.1 ± 7	45.6 ± 11.5
1/1000	0.10	32.5 ± 0.09	79.3 ± 5	573 ± 185
1/1330	0.075	33.1 ± 0.09	79.6 ± 5	1600 ± 707
1/2000	0.050	35.0 ± 0.05	83.0 ± 4	> 3600
	Agrimax™ 5			
1/100	1.0	28.3 ± 0.4	47.4 ± 3	3.5 ± 0.4
1/133	0.75	28.3 ± 0.4	48.2 ± 6	4.5 ± 0.3
1/200	0.50	28.3 ± 0.6	57.0 ± 5	8.3 ± 0.6
1/400	0.25	29.7 ± 0.09	55.3 ± 6	18.6 ± 1.2
1/666	0.15	30.9 ± 0.08	60.2 ± 3	50.1 ± 6.8
1/1000	0.10	31.6 ± 0.04	70.0 ± 5	184 ± 42
1/1330	0.075	33.2 ± 0.12	74.9 ± 7	677 ± 226
1/2000	0.050	33.60 ± 0.04	82.0 ± 6	> 3600

[a] contact angles are on a parafilm surface

Rainfastness. When commercial Prowl® was diluted to 1% with water with the addition of either Agrimax™ 3 added at 0.125% and 0.25% or a commercial sticker based on alkyd resin at 0.25%, all Agrimax™ treatments produced significantly higher recoveries than the commercial sticker formulation. Agrimax™ 5 and 4 also produced similar results. The addition of Agrimax™

3 increased retention by three times (78.8 ± 7.4%) more than the commercial formulation alone (21.3 ± 3.3%). It is interesting to note that lower recoveries were obtained at higher doses of Agrimax™ 3. This trend was confirmed by using 0.5% Agrimax™ 3, when the recovery was (38.3 ± 3.2%). Increased rainfastness at lower adjuvant concentrations suggests that the formulation contains an optimized surfactant system and film forming polymer which will act in opposite directions. The surfactant system will have a washing tendency whereas the polymer will retain the active ingredient. Proper adjustment of the dosage balances these opposing forces.

When adjuvants were added to the concentrate, the retention of Rodeo® was influenced by Agrimax™ 3 and was compared with a commercial sticker. The adjuvants were added to the concentrate followed by dilution to 2.1% a.i. Agrimax™ 3 doubled active ingredients retention (49.4 ± 2.6%) relative to the standard commercial formulation (27.1 ± 1.5). The commercial sticker produced much lower recovery at both 0.125 and 0.5%. Once again, Agrimax™ 3 gave higher (41 ± 4%) retention at 0.25% as compared to the commercial formulation (26.4 ± 5%). The commercial sticker produced only 9.1 ± 2.7% recovery. The wash off effect from the high surfactant levels in the commercial sticker was evident in this study. Rainfastness data for Rodeo® applied on a parafilm surface shows surface properties similar to plant leaf surfaces (2). The results were similar to those obtained for glass surfaces.

An increase in the retention of carbaryl was shown when Agrimax™ 4 was added at the rate of 0.13%, and 0.32% v/v to the end-use dilution (1/200) commercial Sevin®. The retention was increased from 39.2 ± 4% for the commercial formulation to 55.4 ± 7% and 59 ± 8% when Agrimax™ 4 was added at the rate of 0.13%, and 0.32% v/v, respectively.

Greenhouse evaluations. Agrimax™ 3 was evaluated with Bravo™ 500. Aqueous suspensions of Bravo® 500 were prepared at 50 ppm and 10 ppm a.i. Agrimax™ 3 was added to each fungicide at 0.25% v/v. The treatments were sprayed to run off on four week old tomato plants. Check plants were sprayed with water only. After drying, separate samples of 4 replicate plants were exposed to 0, 1, 5 and 10 cm of simulated rainfall. The plants were then inoculated with propagules of *Phytophthora infestans* and incubated. Each plant was evaluated by estimating disease control based on a scale where plants not exhibiting lesions were given a rating of 100% control and the check plants were rated as 0% control. The Agrimax™ 3 showed increased control of late blight on tomatoes from 30% to 60%. Comparative enhancement was more pronounced when the dose of Bravo® 500 active was reduced to 10 ppm.

Field tests. These showed efficacy enhancement by Agrimax™ 3 at 0.25% by volume in a tank mix with commercial Paraquat® and Roundup®, with a doubling of efficacy against Bahia grass and broad leaf weeds, with an extended period of control to 21 days, by the addition of Agrimax™ 3 at 0.25%.

Agrimax™ 3 shows biological enhancement of Roundup®. It is clear that both the rate and ultimate % control were enhanced considerably by the addition of Agrimax™ 3 (0.25% with Roundup® at 1200 g a.i./hectare). When Roundup® was used alone, the maximum effect at 21 days after application were 50% control of Bahia grass and broad leaf weeds. Addition of Agrimax™ 3 enhanced the control as early as 7 days after application (50% control versus 10-25% by commercial Roundup®). Further, at the peak effect, 21 days after application, 100% control was obtained when Agrimax™ 3 was added versus 50% control with commercial Roundup alone.

Interpretations. Agrimax™ 3 and 5, in their concentrated form, are believed to be in a state wherein the system consists of reverse micelles with hydrophobic components as the continuous phase, with the polymer oriented in the core in their coiled state with hydrophobic groups outside. During dilution with water, this first state would go through to a second state in which the reverse micelles would open up, going through a lamellar phase in which the surfactants would orient in a head-to-head and tail-to-tail configuration. The polymer molecules open up to an uncoiled state with its minimum energy conformation. On high dilution, state 2 would further transform to a third state in which the lamellar structure would reorient to form micelles with water as the continuous phase. The polymer would assume a coiled conformation with hydrophilic groups preferably pointing outside.

The above changes can be monitored via viscosity and conductance as a function of dilution. One should see the system going through a maximum region of viscosity corresponding to the lamellar phase. The lamellar region should also show increased conductance in spite of the viscosity being high. Conversely, in a true solution viscosity is inversely proportional to conductance. Thus, a corresponding maximum in conductance and viscosity are consistent with a lamellar structure. The maxima are pronounced for Agrimax™ 3 at about 40% added water.

The hypothesized oil-out micelle initial state for Agrimax™ 3 and 5 would explain their capacity to solubilize high concentrations of certain hydrophobic actives. The film forming capacity of the polymers, with the active contained under the film, is a possible mechanism for enhanced biological activity and rainfastness. Work continues to understand mode of action via cuticular penetration, diffusion and plant translocation.

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LEAF SURFACES OF WHEAT AND RYEGRASS AND DROPLET SPREAD

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Summary. The leaf surfaces of wheat and ryegrass were investigated using scanning electron microscopy. Wheat had stomata and trichomes on both the upper and lower surface. Ryegrass had stomata and trichomes only on the upper leaf surface. There were crystalline waxes on both surfaces of wheat and on the upper surface of ryegrass but the lower surface of ryegrass had amorphous waxes. Water droplets spread most on the lower surface of ryegrass but droplets of four oil-in-water emulsions spread most on the upper surface of ryegrass. Static surface tension of the emulsions had no effect on droplet spread.

INTRODUCTION

Annual ryegrass (*Lolium rigidum* Gaud.) is an important weed of wheat crops in southern Australia. The efficacy of foliar herbicides depends on their ability to be retained, spread over, and then penetrate the leaf surface. The wettability of a leaf is dependent on the roughness of the leaf surface, which may be due to macroscopic (eg. venation), microscopic (eg. trichomes and epidermal cell shape) or ultramicroscopic (eg. wax morphology) factors. The properties of the spray liquid, such as surface tension and viscosity, also have an effect on the spread of a droplet on the leaf (3).

This paper examines the leaf surfaces of wheat and annual ryegrass and compares the spread of droplets of water and a number of oil-in-water emulsions on these leaf surfaces.

METHODS

Spray deposits. Droplets of distilled water were sprayed onto the upper and lower surfaces of wheat and ryegrass using a hand operated spayer fitted with a hollow cone nozzle. Samples of the leaf carrying the droplets were then frozen by plunging them into liquid nitrogen. When frozen the leaf segments were sputter-coated with a layer of gold using an EMSCOPE SP 2000 unit before being examined (still frozen) with a Hitachi 540 scanning electron microscope (SEM).

Leaf surface characteristics. *(a) Microscopic factors*. Wheat cv. Meteor and annual ryegrass were grown in a glasshouse during summer under prevailing light and temperature conditions. When the plants were at stage 15 (Zadoks scale) samples were taken fron the middle section of the youngest mature leaf, fixed in 5% glutaraldehyde, dehydrated using an ethanol series and critical-point-dried. The leaf samples were attached to stubs, sputter-coated with a layer of platinum and examined in the SEM.

(b) Wax structures. To avoid solubilization of wax by ethanol, the wax structures on the leaf surfaces were examined using both air- and freeze-dried samples. The samples were attached to stubs and sputter-coated with platinum before being examined in the SEM.

Droplet spread. 0.5 uL droplets (containing 5.0 g/L flourescein (Harcross Colours) as a marker) of each of 5 solutions were placed on leaf segments. After the droplets had dried the deposit length was measured using a binocular disecting microscope with a graticule. The solutions used were distilled water and 1% (v/v) emulsions of KTRI 8, KTRI 9 (emulsifiable canola oils) and D-C-Trate and Shell EDM (emulsifiable petroleum oils).

Surface Tension. Equilibrium surface tension of each solution was measured using a CAHN DCA analyser.

RESULTS

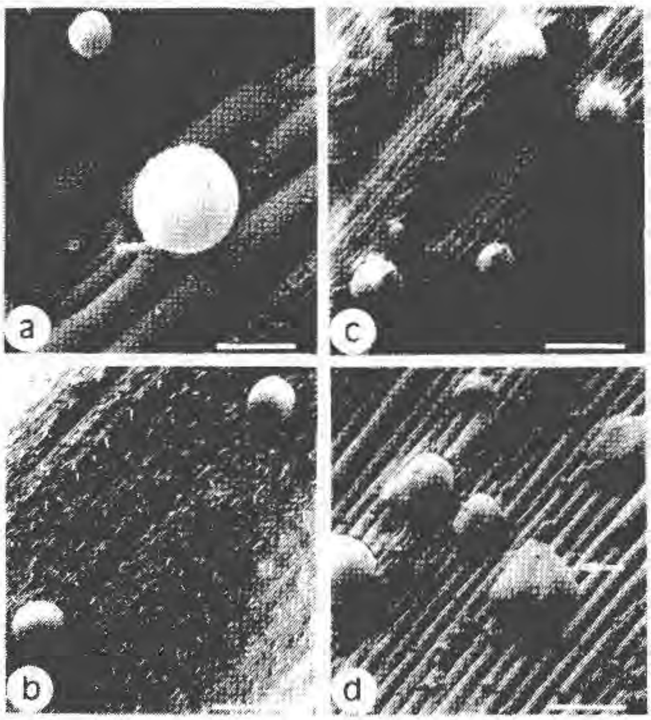

Figure 1. Droplets of water on wheat and ryegrass. (a) upper surface of wheat (bar=43μm), (b) lower surface of wheat (bar=0.6mm), (c) upper surface of ryegrass (bar=250μm), (d) lower surface of ryegrass (bar=176μm).

Spray deposits. Scanning electron micrographs of water droplets on the upper and lower surfaces of wheat and ryegrass are shown in Fig. 1. For both the upper and lower surface of wheat and the lower surface of ryegrass the droplets are spherical and show no spreading. On the lower surface of ryegrass the droplets are flattened and making obvious contact with the leaf (arrow). On the upper surface of ryegrass most of the droplets have been caught by trichomes and are held above the leaf surface.

Leaf surface characteristics. The upper and lower surfaces of wheat and the upper surface of ryegrass had only crystalline wax in platelet form (Table 1). The lower surface of ryegrass was covered by amorphous wax. Wheat stomata were more dense on the upper than on the lower surface. However, ryegrass stomata were found only on the upper surface. On wheat fewer trichomes were found on the upper than on the lower surface. Trichomes were found only on the upper surface of ryegrass. Venation on the upper surface of ryegrass was much more pronounced than that of wheat. On both species venation was evident as parallel ribs on wheat and ryegrass. Neither species showed substantial venation on the lower surface.

Table 1. Surface characteristics of wheat cv. Meteor and annual ryegrass

Surface	Wheat		Ryegrass	
	upper	lower	upper	lower
stomata (mm^{-2})	73.32 ± 2.26	23.87 ± 3.07	119.89 ± 7.65	0.00
trichomes (mm^{-2})	33.39 ± 6.49	96.34 ± 5.58	25.51 ± 5.10	0.00
venation (mm^{-1})	6.82 ± 0.43	0.00	12.12 ± 1.83	0.00
wax type	crystalline	crystalline	crystalline	amorphous

<u>Droplet spread</u>. Table 2 shows that distilled water spread further on the lower surface of ryegrass than on the other three surfaces. For each emulsion the greatest spread was on the upper surface of ryegrass. The spread of each of the solutions was significantly ($p=0.05$) different on the upper and lower surface of wheat.

Table 2. Droplet spread and equilibrium surface tensions

Solution	Surface tension (dyne/cm)	Wheat		Ryegrass	
		upper	lower	upper	lower
H_2O	72.59 ± 0.21	0.92 ± 0.30	0.92 ± 0.30	0.89 ± 0.15	2.42 ± 0.09
KTR18	30.87 ± 0.18	4.79 ± 0.51	3.63 ± 0.30	10.70 ± 1.95	6.83 ± 0.33
KTR19	30.97 ± 0.12	8.40 ± 0.62	6.77 ± 0.77	16.39 ± 1.56	6.63 ± 1.09
Shell EDM	32.07 ± 0.22	10.67 ± 0.49	11.34 ± 0.67	15.50 ± 1.33	9.50 ± 1.00
DC Trate	38.33 ± 0.60	9.05 ± 0.45	8.90 ± 0.53	14.88 ± 1.09	8.71 ± 1.58

On the upper surface of ryegrass there was no significant ($p=0.05$) difference between the spread of KTR19, Shell EDM and DC Trate. On the lower surface of ryegrass there was no significant ($p=0.05$) difference between the spread of KTRI 8, KTRI 9 or D-C-Trate. There was also no difference between the spread of Shell EDM and D-C-Trate on the lower surface of ryegrass. All of the solutions spread almost entirely along the length of the leaf with very little lateral movement. This was most pronounced on the upper surface of ryegrass, where the entire volume of the droplet would often spread along one or two interveinal grooves.

DISCUSSION

When spray droplets land on a leaf surface and are retained, they can either spread across the leaf surface or dry at the point of impact (4). In this study, the water droplets dried at the point of impact on the upper surfaces of wheat and ryegrass and spread on the lower surface of ryegrass. However the droplets of the emulsions spread, to differing degrees, on all the leaf surfaces.

In the present studies the addition of emulsified seed and petroleum oils to water resulted in reduced surface tension and increased spread on the leaf surfaces examined. However, within the group of emulsions there was no obvious relationship between surface tension and droplet spread.This supports the finding of Abbot etal (1) who found that surface tension, critical micelle concentration and contact angle were poor predictors of spread.

However, the nature of the leaf surface had a large effect on spread. For example, water droplets spread most on the lower surface of ryegrass, which was the smoothest of the surfaces examined (amorphous waxes and no stomata or trichomes). The emulsions however, spread most on the upper surface of ryegrass which was, on the basis of stomate number and venation, the 'roughest' leaf surface studied. The greater spread on the upper surface of ryegrass may be due to the 'wicking' effect mentioned by Johnson and Dettre (2). It is more likely that the bulk of the droplets on the upper surface of ryegrass spread along only one or two veins, resulting in a very long, narrow deposit which did not necessarily cover a surface area greater than the shorter, wider deposits formed on the other leaf surfaces. Measurement of the total area covered by a deposit would be a more reliable method of comparing the behaviour of droplets of different formulations on various surfaces. Unpublished data (Levick) indicates that there is an interaction between droplet spread and droplet size, adjuvant concentration and surface structure. The complexities of the interaction of spray formulation and droplet size with waxes and other leaf surface structures need further study in order to clarify the patterns of spread and their effect on spray efficacy.

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POTENTIAL FOR BIOHERBICIDES IN DEVELOPING COUNTRIES

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Summary. Three bioherbicides based on indigenous plant pathogenic fungi are registered commercial products and several bioherbicide research projects are in progress. There is, however, scope for further investigation into bioherbicides for developing country agriculture.

In developing countries, the possibility of mass producing plant pathogens of weeds in low-tech systems at local level is a feasible alternative to high-tech fermentation systems used in the industrialised world. Mass production at the locations and at the time of use would also overcome the need for long shelf-life which is required for commercial products. The tropical regions of the Asia/Pacific area with high humidity and relatively predictable rainfall may be particularly suitable for bioherbicide development and use.

INTRODUCTION

Bioherbicides are biological herbicides in which the active ingredient is a microorganism. The bioherbicide technique uses inundative doses of plant pathogens to create artificial and localised epidemics each season. (See (1) for recent reviews of the subject).

Up to this stage, bioherbicides have utilised indigenous or naturally occurring pathogens, although the use of exotic microorganisms is feasible, but requires adequate host range testing.

COMMERCIAL PRODUCTS

Three commercial bioherbicides Collego®, Devine® and Biomal® are registered products in North America. They utilise naturally occurring fungi and are thus also referred to as mycoherbicides.

Commercial products such as these are conveniently produced en masse by submerged culture fermentation then, separation, drying and storage, but this requires high capital expenditure.

In addition fermentation time competes with other potential uses for fermenters. For example, production of high value products such as antibiotics or hormones. Moreover not all microorganisms will reproduce in submerged culture. Oxygen mass transfer is a major problem for aerobic processes as its solubility in water is only about 6 ppm (2). While the use of solid substrate techniques may overcome these problems, these methods are generally regarded as too labour intensive and therefore too expensive in the industrialised world.

The bioherbicides which have so far been produced commercially have limited host ranges. This is operationally useful and ecologically desirable but it restricts the market size for the products and therefore may be a disincentive for commercial investment in bioherbicides.

Ideally commercial products should have long shelf-life. Application sites may be considerable distances from place of manufacture and making a product at a time suitable to the manufacturer is desirable rather than in response to an urgent need by potential users of the product.

Therefore commercial producers aim for a minimum shelf-life of a year. However the bioherbicide, Devine®, has a shelf-life of only six weeks in refrigerated storage, but it is feasible to distribute and market the product because of the limited target area: Milkweed vine (*Morrenia odorata*) infested areas in citrus groves in Florida.

Mycoherbicides generally have a requirement for dew or high humidity for satisfactory results. Collego® and Devine® are both used in irrigated rice and citrus orchards agriculture and this is part of the reason for their success. Biomal® is used in situations where rainfall events are likely and can be confidently predicted in the mid-west wheat growing region of Canada.

A moisture requirement has hampered the development of several potential mycoherbicides in dryland agriculture in temperate regions. Thus a great deal of research effort has recently been placed on the development of formulations to overcome this dew requirement. However complex formulations may add considerably to the cost of products.

DEVELOPING COUNTRIES

The use of bioherbicides has been relatively neglected in developing countries. The outstanding exception to this is the product, Lu-bao No. 2, based on the fungus *Colletotrichum gloeosporioides*, to control dodder, *Cuscuta* sp., in the People's Republic of China which was first used in 1963 as "Lu-bao No. 1". However, recent interest has focussed on potential mycoherbicides in a number of developing countries. For example: *Rottboellia cochinchinensis* in Thailand (research supported by the International Institute of Biological Control, U.K., this is also a major weed in Central America); *Striga* sp. control with *Fusarium* spp. in Ghana (research supported by University of Hohenheim, Germany).

Apart from the environmentally desirable aspects of using naturally occurring microorganisms over synthetic chemicals, the substitution of these products for imported herbicides would lead to valuable savings in foreign exchange.

Some of the factors which limit bioherbicide production and use in developed countries may not apply in developing countries:

<u>Mass production</u>. There is a tradition of food production by fermentation techniques in many developing countries, particularly in south-east Asia. Many of these fermentation systems use solid substrates and thus overcome the problem of oxygen limitation in submerged culture fermentation. Moreover they do not require the same capital investment as fermenters and the media used in such systems may be derived from waste products of food production or straw, for instance.

<u>Shelf life</u>. Because of the rapid multiplication rates of microorganisms in combination with the potential to produce them in local solid-state fermentation systems, the need for long shelf life diminishes. Products could be made in relatively small quantities locally to satisfy local needs.

<u>Moisture requirements</u>. Many developing countries, particularly in the Asia/Pacific area, are located in tropical regions where humidity is high and rainfall relatively predictable. Moreover many crops in developing countries are irrigated. Thus the moisture limitations imposed on mycoherbicides in dryland temperate agriculture often will not apply in developing countries.

Availability of suitable microorganisms. Plant pathogens associated with weeds have been poorly collected even in countries with large numbers of publicly supported research personnel and extensive laboratory facilities. Clearly the first steps to be taken would be the nomination of the most important weed species, then the deliberate searching for pathogens, their isolation, identification, virulence testing and host-specificity testing.

The steps to follow are then, defining optimal conditions for infection and disease development, mass production and field testing.

THE FUTURE

Successful bioherbicide projects require collaboration between plant pathologists, weed scientists and fermentation specialists in the public sector. This is true for developing countries, just as it has been in developed agricultures.

Cooperative projects between scientists with experience in bioherbicide development and interested plant protection research groups in developing countries should accelerate the adoption of bioherbicides as alternatives to conventional herbicides and manual weed control.

An International Bioherbicide Group (I.B.G.) has been established to foster communication and cooperative projects on bioherbicides and assist transfer of technology that will assure availability of bioherbicides.

This cooperation also has potential benefits for developed agricultures, including the introduction of alternative fermentation techniques for mass production of biocontrol agents and alternatives to the commercial model of bioherbicide production.

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PUCCINIA CARDUI-PYCNOCEPHALI, A POTENTIAL AGENT FOR THE BIOLOGICAL CONTROL OF SLENDER THISTLES IN AUSTRALIA

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Summary. Progress towards the biological control of the slender thistles, *Carduus pycnocephalus* and *C. tenuiflorus* with the rust *Puccinia cardui-pycnocephali* is reported. A search for virulent strains of rust on both slender thistles was made from extensive collections in Southern Europe. Of these, some strains were found that are especially pathogenic. The effect of selected strains in decreasing the reproductive capacity of these winter annuals is documented. Recently, two selected strains have been imported into quarantine in Australia for further host specificity testing.

INTRODUCTION

The closely related slender thistles, *Carduus pycnocephalus* and *C. tenuiflorus*, are major weeds of sheep-grazed pastures. Both are winter annuals of Mediterranean origin that reproduce only by seeds. These two species are now widely distributed in New South Wales, Victoria (8.25 million hectares) and Tasmania, and also occur in South Australia, south-western Western Australia and south-eastern Queensland (10). High densities of slender thistles greatly reduce pasture availability and yield (by up to 66% in Victoria; 9), thereby causing notable economic losses.

Biological control represents a valuable strategy for long-term management of slender thistles because both these species are largely a problem of disturbed pastures and wastelands. Initially, research has focussed on the use of insects, which have not effectively controlled slender thistle populations in North America (4). In this regard, studies on the population dynamics of slender thistles in their native Mediterranean environment showed a remarkable population stability over sites and over years (12). Extensive surveys detected more than twenty insect species associated with slender thistles. However, by themselves, none of these appeared to be a limiting factor for these weed populations (12), a result which possibly reflects the short life span of the hosts and their partial asynchrony with the main period of insect activity (3).

Consequently, research efforts have shifted towards the evaluation of potentially useful pathogens, as they often show a short generation time, high reproductive capacity and dispersal, and a phenology matched to that of their hosts. Of these, the autoecious rust, *Puccinia cardui-pycnocephali*, is commonly found on slender thistles throughout the Mediterranean basin. Although at least one strain of this pathogen already occurs in Australia (9), it is not very effective in reducing growth or seeding of Australian genotypes of the two slender thistles. However, a significant decrease in growth and capitula production was found when glasshouse grown rosettes of Australian *C. pycnocephalus* were repeatedly inoculated with an isolate collected in southern France (8). This suggested that effective isolates could be found in Europe for the biological control of slender thistles in Australia.

METHODS

Rust surveys. Extensive field surveys for isolates of the rust were carried out in France, Italy, Spain and the former Yugoslavia in 1989-91. Two surveys were made in May 1989 in north-western Spain and Italy. Similar surveys were made in central-southern and north-eastern Spain and in Yugoslavia in 1990-91. Surveys in southern France were made on a more regular basis due to the proximity of sites to the CSIRO laboratory at Montpellier. Occurrence and abundance of the rust were scored on 50 to 100 plants per site using a visual scale similar to that used by Sheppard *et al.* (12).

Inoculation procedures. Glasshouse grown rosettes were inoculated at the 4-6 leaf stage with urediniospores using the method described by Hasan (7). Visual assessment of disease symptoms was made using a five point scale, as follows: 0- Immune (no symptoms); 1- Resistant (visible chlorosis and necrosis on leaves, no uredinia); 2- Moderately resistant (chlorotic and necrotic spots associated with a few minute pustules); 3- Moderately susceptible (numerous small and eruptive uredinia often associated with chlorotic halos) and, 4- Susceptible (leaves covered with eruptive uredinia, no plant reaction).

Effectiveness of the rust. An inoculation experiment in the field was designed to evaluate the effect of the rust on plants of both species of slender thistles. Two fully randomized plots were established with potted plants from 7 sites in Australia. Sterilised soil and timed drip-watering were identical for the 2 plots. Plants in one plot served as control and those in the other plot, situated 30 m away, were inoculated (at the 6-8 leaf stage) once only with the isolate FR3 to simulate natural levels of infection. Inoculation was achieved by spraying a suspension of urediniospores and water (1 mg/20 mL) onto the plants. Plants were monitored every fortnight for disease intensity, rosette growth and plant height. Ripe capitula were collected twice daily during the flowering period and seed number and viability assessed. Biomass of whole dried plants was measured after harvest. These data were analysed using Anovas.

RESULTS AND DISCUSSION

Rust surveys and selection of isolates. High levels and rates of infection by the rust were apparent at 11.6% of the 104 sites surveyed, especially in central and southern Spain. Overall, rust infection was noticed at 57.7% of sites visited, covering a wide range of environmental situations. Isolates of the rust were collected from these sites and evaluated in the glasshouse for pathogenicity on both species of slender thistles, including various Australian plant genotypes. The pathogenicity of isolates of *Puccinia cardui-pycnocephali* is highly variable and Australian accessions of both slender thistles present a continuum of infection type responses to the isolates within this rust fungus (Table 1).

Some isolates are extremely virulent on Australian genotypes of slender thistles. However, while isolates of rust collected from either one of the two host species will attack the other host, the isolates are most pathogenic and produce the severest symptoms on the host species from which they were originally collected. This was observed also for two isolates collected from *C. tenuiflorus* in Australia and could explain why the rust occurs particularly on this species in south-eastern Australia (9). These results indicated that it will be necessary to introduce and release at least two isolates initially, with the aim of affecting plants of both species of slender thistles. By attempting to overcome the genetic heterogeneity of these weed species for resistance to the pathogen, the strategy used will be likely to minimize the problems raised by the existence of resistant biotypes (2).

Table 1. Summary of pathogenicity of *Puccinia cardui-pycnocephali* isolates from southern Europe on Australian slender thistles

Isolates collected from:	Infection type[a] on:		Number of isolates
	Carduus pycnocephalus	*Carduus tenuiflorus*	
Carduus pycnocephalus	4	0	1
	4	2	3
	4	3	2
	3	0	4
	1	5	3
	3	2	3
	1	0	
Carduus tenuiflorus	2	4	3
	2	3	3
	1	3	7
	0	1	4

[a] Infection type from 0= immune to 4= susceptible, heavy production of uredinia.

For *C. tenuiflorus*, comparative assessments made between two isolates of the rust already present in Australia and three of the highest ranking isolates from southern Europe suggested that none of these isolates was significantly more virulent on Australian plants of *C. tenuiflorus* than the other, as measured by the number of uredinia produced per unit of leaf area under uniform conditions (Sichez, unpublished data). However, isolate FR3 collected from Salin de Badon (southern France) was more agressive, producing the heaviest infection (number and amount of spores) on several Australian accessions of *C. tenuiflorus*. Thus, it was selected for further screening and subsequent host-specificity testing. Choice of this isolate was strengthened by the fact that it sporulated profusely on all plants collected from 10 sites in New South Wales and Western Australia. For *C. pycnocephalus*, isolate IT2 from Terlizzi (southern Italy) was by far the most virulent isolate on Australian plants. All plants collected from 11 geographically well separated sites in Australia showed high levels of infection after inoculation with this isolate. Hence it was chosen for the control of this species of slender thistle.

Impact of the rust on slender thistles. Uredinia first appeared on plants 15 days after inoculation. At least 6 generations of spores were produced over the course of the experiment. The highest levels of infection were recorded mainly on rosettes of *C. tenuiflorus* for which as many as 1560 uredinia per plant were counted. Plant height, biomass and the production of viable seeds of rusted plants were all significantly reduced (Table 2).

However, the two thistle species responded differentially to isolate FR3 of the rust ($P=0.001$), while within a thistle species, there was evidence of some geographic differences in the degree to which production of viable seed was reduced (Fig. 1; $P=0.001$). These results confirm the importance of introducing and releasing at least 2 isolates initially.

Table 2. Effect of *Puccinia cardui-pycnocephali* infection on plant height, dry weight and production of viable seeds of the slender thistles, *Carduus pycnocephalus* and *C. tenuiflorus*. Data from an outdoors inoculation experiment. Means (s.e.) are presented. Pairwise means are statistically different at the 1% level using one way Anova.

Species	Treatment	N	Height (cm)		Dry weight (g)		Seed production	
C. pycnocephalus	control	20	87.30	(4.47)	19.36	(1.06)	173.97	(22.95)
	inoculated	20	38.80	(2.72)	11.27	(0.78)	32.31	(10.19)
C. tenuiflorus	control	21	52.90	(3.71)	16.85	(0.79)	84.44	(11.82)
	inoculated	21	25.43	(4.01)	7.26	(0.63)	20.65	(8.30)

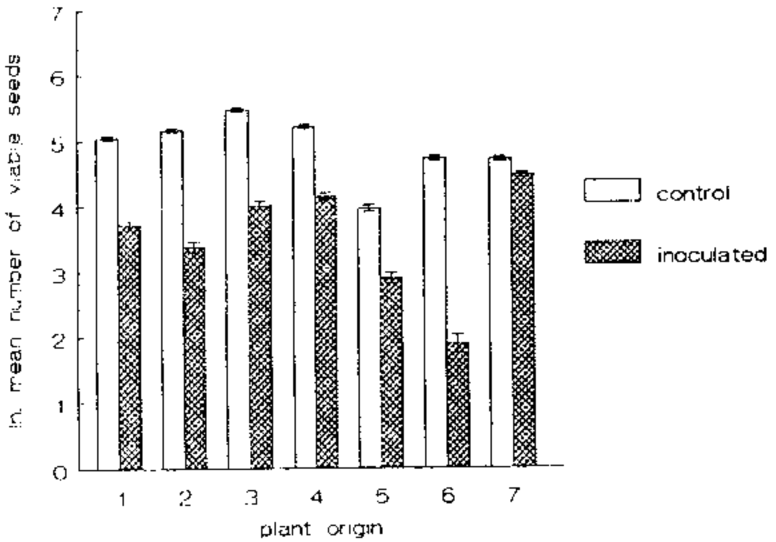

Figure 1. Production of viable seeds of slender thistles in relation to rust infection and plant origin. Origin 1 to 4: *C. pycnocephalus* plants collected from Denmark, Manjimup, Boyup Brook and Bridgetown (WA); 5 replicate plants per treatment and origin were used. Origin 5 to 7: *C. tenuiflorus* plants collected from Yaouk (NSW), Albany and Manjimup (WA); 7 replicate plants per treatment and origin were used.

Another field inoculation experiment confirmed that the selected isolates FR3 and IT2 curtailed the reproductive capacity of Australian genotypes of both slender thistles, even in the absence of plant competition (Chaboudez, unpublished data). As slender thistles are annuals, the significant reduction in seed production caused by rust infection is likely to reduce the size of infestations. However, the maintenance of a competitive perennial pasture during the limited period when slender thistles germinate (autumn rainfalls) should have a synergistic effect in controlling weed density, as has been shown for several other weed-pathogen systems (6, 11).

On the basis of the successful host specificity testing of the 2 candidate isolates, authorisation was given to import these into quarantine in Australia. From the actual distribution of the rust in Australia, it is anticipated that the introduced isolates will probably establish and spread under the same environmental conditions, if release is approved. These isolates have the potential to decrease vigour and reproductive capacity of slender thistles. However, the extent to which it will affect thistle density and thereby provide substantial control will ultimately depend on how well these biological control measures are integrated into pasture management (1, 5, 13).

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THE ESTABLISHMENT OF *UROMYCES HELIOTROPII* SRED., A BIOLOGICAL CONTROL AGENT OF *HELIOTROPIUM EUROPAEUM L.*

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Summary. The results of releases of the rust fungus, *U. heliotropii*, against the summer annual weed common heliotrope, *H. europaeum*, in Australia are described. Of 19 separate releases of urediniospores made at 13 sites in NSW, SA, Vic. and WA over three years, 11 showed local spread of the disease to distances up to 500 m. Of these releases, 13 led to the production of teliospores. To date, six release sites have been monitored in the season following teliospore production and three have shown natural re-infection via the production of spermogonia and aecia. Releases have been most successful in South Australia.

INTRODUCTION

Common heliotrope, *Heliotropium europaeum* L. (Boraginaceae), is a summer-growing, herbaceous annual plant from Mediterranean Europe to the Middle East. The plant has become a weed in southern Australia where it often dominates fallow, disturbed or ploughed land from December to April when it can also be an important component of annual pastures. The foliage contains high levels of pyrrolizidine alkaloids (11), which can poison grazing animals and, as such, the weed causes substantial economic stock losses in years of high abundance (2). Infestations of the plant also take moisture from the soil in the months prior to sowing, therefore affecting subsequent crops (4). The seeds germinate on bare soil or in light vegetation when soil temperatures exceed 24°C following spring and summer rainfall (10). The plant produces flowers and seeds concurrently with vegetative growth, soon after germination, that create a persistent seed bank (3) of up to 300,000 seeds/m2, and dies in autumn or following water stress.

Uromyces heliotropii Sred., is a macrocyclic, autoecious rust fungus native to Eurasia (5). This rust is specific to *H. europaeum* and some closely related European species (8). During testing some limited development occurred on the Australian natives *H. crispatum* and *H. pressiana*. However, *H. crispatum* grows in winter in regions unsuitable for the rust, while the spores produced on *H. pressiana* proved non-viable (8). Studies in Montpellier (southern France) have shown that the pathogen can both kill young seedlings and reduce viable seed production of mature plants (7). The rust has two relatively long-lived spore types. The brown urediniospores are wind dispersed, being produced only during the summer, and lead to either the further production of uredinia on healthy plants or the production of black telia on stressed or senescing plants. The telia produce teliospores that can over winter on plant fragments that remain in the litter layer and re-infect plants the following season producing honey coloured spermogonia and then orange aecia. The environmental requirements for the germination and survival of these spores have been studied under laboratory conditions (6,7,9). AQIS and ANPWS approved release of *U. heliotropii* in early 1991. This paper documents the results of releases made to date, and discusses conditions for successful establishment.

METHODS

Table 1. Rust incidence following inoculations of common heliotrope with *U. heliotropii* urediniospores; (i) methods as described or modified (*) in text; (ii) maximum spread from release point; (iii) classes of disease intensity in the area of spread (see text); *i* = irrigated site; *nd* = data not yet available.

Site		Inoculation		Disease	Spread (m) (ii)	Intensity (iii)	Telia	Aecia (yr+1)
		Date	Method (i)					
Gnowangerup WA		1/91	1,2	yes	30	a	yes	no
		1/92	1,2	yes	22	c	yes	no
		1/93	1	yes	4	c	yes	*nd*
Jugiong NSW,	area 1	1.91	1,2	yes	100	d	yes	yes
	area 2	3/92	2	no	-	-	-	-
	area 3	1/93	3	yes	80	b	yes	*nd*
Trangie NSW,	area 1	1/92	1	yes	500	b	yes	no
	area 2	2/93	3	yes	0	a	yes	*nd*
Parkes NSW		1/93	1,3	yes	0	a	no	*nd*
Temora NSW*i*		1/93	3	no	-	-	-	-
Young NSW		2/93	3*	yes	5	b	yes	*nd*
Barham NSW*i*		1/93	1,3	no	-	-	-	-
Dookie VIC		1/93	1,3	no	-	-	-	-
Tailem Bend SA,	area 1	1/92	1,2	yes	2	b	yes	yes
	*i*area 2	1/93	3	yes	*nd*	*nd*	yes	*nd*
Kadina SA		1/93	3	no	0	a	no	*nd*
Maitland SA		1/93	1,3	yes	10	b	yes	*nd*
Streaky Bay SA		1/93	1,3	yes	5	b	yes	*nd*
Minnipa SA*i*		1/92	1,2	yes	100	c	yes	yes

Releases of urediniospores were made from December to March in 1991, 1992 and 1993 at six sites in NSW, five sites in South Australia, and one site in each of Victoria and Western Australia (Table 1). With the aim of maximising the production of inoculum at the site, the plants selected for inoculation bore many green leaves. Inoculation took place in late-afternoon to early-evening with 2-9 week old spores collected from a laboratory culture. Three methods of release were used: (i) 30 mg of spores were brushed, using a paint brush, on to the upper surface of all leaves of 6-16 plants which were at least 15 cm high and with few mature seeds. The plants were watered underneath and then sprayed with a fine mist of water following inoculation. Small polythene covers (also sprayed with water on the inside) were placed over each plant for 12 hours; (ii) 30 mg of spores were mixed with 50 mL of water just prior to inoculation and applied using a hand-held aerosol sprayer to 6-8 plants. Small polythene covers were also placed over these plants for 12 hours; (iii) 200 mg of spores were mixed with 125 mL of talc and applied to pre-watered plants over a 1x5 m area using a hand held pump-action duster. Following inoculation plants were covered with a fine mist of water and a moistened clear plastic sheet which was again left until morning. Table 1 outlines where these methods were used. No attempt was made to assess impact in the first year. Environmental data loggers were installed at the five longest studied sites (those in Table 2) for comparison of conditions for infection.

In the first season of inoculation, 10 uninoculated plants of similar size and development were chosen in the immediate surrounding area. Inoculated and uninoculated plants were then monitored fortnightly. For these plants, height was measured and the total number of leaves and the number of cymes bearing seeds counted. The distance of spread of rust symptoms was also monitored at the same time by examining surrounding plants and searching at increasing distances from the points of release until either no further spread was observed or the limit of the weed infestation was reached. During these examinations, rust intensity was assessed per site in four categories: (a) no plants infected; (b) few plants infected; (c) most plants infected; and (d) all plants infected. Where possible, other infestations of the weed within a 2-3 km radius were also examined. The presence of teliospores was also noted.

In late spring of the year following inoculation, each site was visited to clear or plough a core area to encourage germination of the weed. From December monthly visits were made to each site. Plant density was measured in the core area, and a random sample of 25 plants was collected to count the number of leaves, cymes and developing seeds. The percentage of plants infected by aeciospores and urediniospores was recorded on each visit.

RESULTS AND DISCUSSION

Of the three inoculation methods used, 1 was reliable, but proved time consuming per treated plant, 2 provided poor results in the field and proved impractical as the nozzle regularly froze up during application; while 3 was as effective per plant, but allowed many more plants to be treated for the same effort. A modified method 3 without an application of water or plastic sheeting also worked very effectively in a gully site at Young.

Of the 19 releases of urediniospores, 14 led to significant infection, 13 showed significant teliospore production and 11 had some spread of the pathogen within the season (Table 1). At three of the five sites where inoculation was unsuccessful, the spores used had very low viability. Subsequent tests showed that the spores over 5 weeks old, which were stored in a desiccator at 0 to -7°C, had less than 20% viability. At the other two sites, ineffective inoculation method was the cause at Jugiong in 1992 and early plant death from the leaf blotch, *Cercospora taurica* Tranzschel, prevented infection at Temora.

The distance of spread or the intensity of the disease were not associated with any of the plant characteristics measured at each site. At Parkes spread and telia production were prevented by an outbreak of *C. taurica* killing the infestation. At many sites spread was limited by a lack of available plants following initial infection. This resulted from either small weed infestation size (Jugiong in 1991, Gnowangerup in 1992 and Minnipa), or heavy plant death as a result of early (Gnowangerup in 1991) or late season (Jugiong in 1993 and Trangie in 1993) water stress. To combat this, controlled irrigation was used at four sites (Table 1). This encouraged the rust-weed interaction at Minnipa, however at two other sites infection failed due to other causes. The fourth site, Tailem Bend in 1993, still requires assessment. The rust showed >50 m spread at four sites. At Trangie in 1992 and Jugiong in 1993 patches of infection were associated with the prevailing wind and heavy rain soon after the first pustules were produced. At Jugiong in 1991 and Minnipa less directional spread and high infection intensity (Table 1) were associated with late season rains in March. At Gnowangerup in 1991 aecia were observed in the same year as inoculation. Early water stress had caused the production of telia and a later cohort of the weed became reinfected.

Successful establishment, as indicated by the presence of spermogonia and aecia in the season following inoculation, has now been observed at three of the six sites that have been followed so far (Table 2). At Gnowangerup in WA re-infection in the following year has failed two years running despite the weed increasing in abundance size from one year to the next. At Jugiong (NSW) only a few aecia were found in the next year. Severe flooding had occurred during the preceding winter and common heliotrope covered only a quarter of the previous year's inoculation zone due to the growth of other vegetation The rust did not survive even though common heliotrope covered the surrounding hillsides. At Trangie (NSW) there was no re-infection despite an abundance of healthy plants early in the season (Table 2). The only success has been in South Australia. At Tailem Bend in 1992, 6.3% of plants produced telia in the release area in the first year. In 1993, 1.3% of plants of the next generation produced aecia leading to 24% of plants with uredinia by March (Table 2). The disease had spread 7 m. At Minnipa, 100 % of plants produced telia 1992, 6% had aecia in January 1993, and 19% had uredinia by March. The disease here had spread 400 m in one direction and 170 m in another. While a slow build up of the disease occurred at Tailem Bend, the disease situation at Minnipa was potentially epidemic, until flooding destroyed 44% of plants in February 1993. The disease is currently recovering at this site.

Table 2. Spread of *U. heliotropii* away from previous year's diseased area and characteristics of *H. europaeum* during the period of aecia observation at sites followed over two years (nd = no data available)

Site	Date	Aecia		Other spore types			Plant characteristics/m^2		
		% Plants infected	Spread (m)	Uredinia /telia	% Plants infected	Spread (m)	Plant density	Leaf density	Seed density
Gnowangerup WA	92	0	-	-	-	-	c.200	12200	3680
	93	0	-	-	-	-	212	4452	77168
Jugiong NSW	92	<0.01	0	none	-	-	nd	nd	nd
Trangie NSW	93	0	-	-	-	-	272	9836	18170
Tailem Bend SA	93	1.3	0	U,T	24	5	892	21140	60656
Minnipa SA[1]	93	6	400	U,T	19	170	148	2738	8702

The spread of *U. heliotropii*, thus far, has contrasted markedly to the success of *P. chondrillina* released against skeleton weed. In that case only one year was required for the disease to cover south-eastern Australia (1). The local rate of spread of *P. chondrillina* within a site was comparable to the best cases with *U. heliotropii*, but this rust has so far failed to make the rapid jump to more distant weed infestations and most of the ground gained in one season is lost when common heliotrope re-appears. Common heliotrope is short lived compared to skeleton weed and furthermore, heliotrope infestations are more ephemeral in time. Therefore its pathogen is limited in the time it has available to multiply on one host before it must infect others, and often these do not appear for the next 7 months and are not necessarily close by. *U. heliotropii is* dependent on its teliospores to infect future generations of the weed, while *P. chondrillina*, with a perennial host, is not.

The continuation of infection through the summer depends on the survival rate of spores in Australia. Previous seasons teliospores would not survive the summer and, urediniospore survival is less than a month at temperatures above 30°C (S. Hasan, unpublished data). Summer daytime temperatures can stay at these levels for extended periods, while humid conditions necessary for infection may often be separated by more than a month. However, the differences between sites in Table 2, must be caused by the conditions necessary for teliospore germination. While there are clear environmental differences between the sites in NSW, WA and South Australia, these have not been used, so far, to understand why releases in South Australia have been more successful. There was little evidence to suggest that teliospores can be dispersed away from the site of production. This biological control agent probably requires consecutive generations of hosts in the same area in order to show good local survival and explosive outbreaks. Unfortunately, observations suggest conditions which appear favourable for the rust can also produce destructive outbreaks of other natural enemies of the weed such as *C. taurica* and the moth *Utethesia pulchelloides* Hamps.

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BIOLOGICAL CONTROL OF BROOM, *CYTISUS SCOPARIUS*, IN AUSTRALIA

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Summary. Broom, *Cytisus scoparius*, is an important weed in the Barrington Tops, NSW. Stands consist of mature, thick-stemmed plants and high seed bank levels occurring in the soil. The main requirement is for agents damaging to established plants and destroying seedlings. Such agents exist in Europe but they may not possess the necessary host restriction whilst tagasaste, *Chamaecytisus palmensis*, is promoted as a fodder. Therefore, biological control of broom has commenced with the release of the moth *Leucoptera spartifoliella* and specificity testing of the plant louse *Arytainilla spartiophila*. Both damage young shoots and should reduce growth and seeding.

INTRODUCTION

Broom, *Cytisus scoparius* (L.) Link (Fabaceae), a native of Europe, is a weed in temperate Australia. Infestations occur in moderate to high rainfall regions over wide areas of Victoria and northern Tasmania and in scattered areas of New South Wales and South Australia (25). The plant is a major problem in open forests and woodland in the Barrington Tops region of New South Wales where dense, tall, mature stands of the weed cover 10,000 hectares (39) preventing access into the National Park and State forest (27). Similar mature stands of broom occur in the Shoalhaven Valley near Braidwood, New South Wales. At both localities the thick-stemmed, woody plants have stored considerable reserves in their stems and roots. High seed bank levels occur in the soil, beneath the stands in Australia as they do in Europe (20, 26).

C. scoparius belongs to the fabaceous tribe Genisteae which is divided into two sub-tribes, Lupininae containing only *Lupinus* and Genistinae containing all other genera including *Genista* and *Cytisus* (5). Tagasaste or tree lucerne, *Chamaecytisus palmensis* (Christ) Bisby and Nicholls, which belongs to the *Cytisus* group within the sub-tribe and which has been promoted as a fodder shrub in New Zealand and Australia (21, 22, 23, 28, 34) is the most closely related plant of importance in Australia. Fodder lupins, *Lupinus* spp., are more important but less closely related to broom. No other crop or fodder Fabaceae grown in Australia belong to the same tribe and there are no Australian native plants in the tribe.

BIOLOGICAL CONTROL AGENTS

Biological control of broom has been undertaken previously by the USA and more recently by New Zealand. Both countries have large areas infested by the weed. The Australian program is, at present, using insects whose specificity has been studied for America and New Zealand (1, 2, 3, 13, 24, 30, 31, 33). The biology of, and damage caused by, the great majority of insects infesting broom has been described in detail in England during a long series of ecological studies (36) but less is known about insects damaging broom in southern Europe. Waloff and Richards (37) demonstrated the impact of insects on growth, longevity and reproduction of broom in England but were unable to distinguish which insect species were responsible.

Two insects have been selected initially as biological control agents for broom in Australia. The first, *Leucoptera spartifoliella* (Hübner), has recently been released after additional host specificity testing confirmed its host restriction (Cullen unpubl.). The larvae of this small lyonettid moth mine the epidermis of green twigs (36). The second, *Arytainilla spartiophila* (Förster), is a sap-sucking psyllid which also infests new growth (36, 40). Other agents used by America or New Zealand or under investigation now by New Zealand and Australia include seed feeders, the bruchid, *Bruchidius villosus* F., and the weevil, *Apion fuscirostre* (F.), the defoliating geometrid moth *Chesias legatella* (Schiff.), the stem and leaf-tying oecophorid moths, *Agonopteryx* spp., the root nodule feeding weevil, *Sitona regensteinensis* Herbst., the stem galling eriophyid mite *Aceria genistae* (Nalepa) and the stem mining weevil, *Apion immune* Kirby (1, 9, 10, 11, 12, 13, 14, 24, 31, 32, 33, 41).

Except for *A. immune* and *L. spartifoliella* none of these arthropods directly destroy the stems or roots. *A. immune* is recorded on *Cytisus* and *Genista* species (17) and subsequent specificity testing in the laboratory indicated that it could infest tagasaste. This even occurred during field tests although the level of attack on *C. palmensis* was lower than on *C. scoparius* (9, 10, 11, 14). Thus, for this stem feeding weevil both previous records and specificity testing indicate a broad host range in the Genistinae. Other insects which destroy or cause damage to the stems and roots of broom are known in Europe. The most damaging is the scolytid gallery maker, *Hylastinus obscurus* (Marsh.) (36) but as this insect is a pest of perennial clovers, *Trifolium* spp. and lucerne, *Medicago sativa* L. (4) it cannot be introduced into Australia. Another scolytid, *Phloeophthorus rhododactylus* (Marsh.) feeds on dead and dying wood (36) and would therefore be of no value as an agent. Another *Apion* species, *A. striatum* Kirby, mines the stems in a similar way to *A. immune* but adults are recorded on three genera in the Genistinae (17). The cerambycid stem borer, *Deilus fugax* (Olivier), has a broad host range in the Genistinae (35). Even the eriophyid mite, *A. genistae*, which belongs to a group of mites noted for their high specificity and which can produce large galls on broom stems, has a host range considered to include several genera in the Genistinae (7, 8). The extent of the host range of the eriophyid on broom is being clarified by testing in Europe (12). The weevil, *Polydrosus confluens* Stephens, the only insect known to cause direct damage to the roots of broom in Europe, may have a broad host range in the Genistinae (15). Another weevil, *Lixus spartii* Olivier, probably has root feeding larvae but its adults are also recorded from several genera of the Genistinae (16).

Destruction of stems and roots of broom would result in rapid control of existing broom plants. However, successful biological control of broom will require control of seedlings as well as established bushes. Research in England and in France is at present attempting to establish which agents affect seedling survival (12). This research began in 1992 and little obvious damage was caused by insects during that year although many seedlings and young plants were killed by a fungus, *Phomopsis* sp.

DISCUSSION

Although the introduction of seed and pod feeders, defoliators and leaf tiers, sap suckers and root nodule feeders would probably reduce growth and seed production of *C. scoparius*, as they do in Europe (37), it would be some time before there was any change in plant density in the mature broom stands in Australia. *L. spartifoliella* should cause damage to new growth on existing plants and should be as damaging in some areas as it has been in New Zealand, the USA and Europe (13, 24, 29, 36). Agents that reduce reserves in the stems and roots should achieve control of established plants more rapidly. For instance, Australian cerambycids girdling and then boring into thick stems of broom have caused an opening out of the stand canopy at Braidwood. Four cerambycids have been reared from the girdled stems, the larger *Uracanthus* *bivittata* Newman and *Strongylurus arduus* Elliott and McDonald are probably causing the girdling and the smaller *Pentacosmia scoparia* Newman and *Sybra acuta* Pascoe are probably secondary borers in the dead, girdled stems. Similar girdling damage has not been observed in the Barrington Tops region. Furthermore, biological control work in South Africa against *Sesbania punicea* (Cav.) Benth., another shrubby fabaceous tree similar to broom, has shown that, although seed feeding agents have reduced seed production by up to 99%, they have had little effect on densities of stands of mature plants. On the other hand, a stem boring weevil has caused marked reduction of densities in thickets of this weed (18, 19).

Because most potential agents for *C. scoparius* in Europe appear to have a broad host range within the Genistinae, *C. palmensis* is at risk from them. At the present time any potential agent infesting tagasaste during field or perhaps even laboratory specificity testing would be unlikely to receive approval for introduction to Australia. Thus, tagasaste is the critical plant species (38) for the biological control of broom but in most cases this testing has not yet been done. However, the limited number of agents damaging stems and roots and their broader host range mean that, for the present, reduction in plant density will probably have to rely on agents that damage other parts of the plant. These agents are being investigated further to determine their host specificity. If tagasaste was no longer promoted as a fodder shrub in Australia then more effective insects should be able to be introduced and released as the host range for the stem and root feeders recorded in the field does, except for the scolytid *H. obscurus*, indicate a restriction to the sub-tribe Genistinae and so they would be unlikely to infest *Lupinus* spp. or Australian natives in tribes related to the Genisteae in the Fabaceae. Furthermore, tagasaste is causing increasing concern as an environmental weed in Victoria (6) and has the potential to become an increasing problem in all areas where it is now grown. If eventually tagasaste should be considered a weed this would relax present restrictions and then biological control of broom could become even more probable than at present.

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EFFECTIVENESS OF *RHINOCYLLUS CONICUS* AS A BIOLOGICAL CONTROL AGENT FOR NODDING THISTLE, *CARDUUS NUTANS*, IN AUSTRALIA

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Summary. Data are presented from Glencoe, NSW, on the phenology of flowering of nodding thistle, *Carduus nutans*, and the effectiveness of the biocontrol agent, *Rhinocyllus conicus*. The period of activity of the weevil is restricted to the first two months of the plant's flowering period, which often extends for a further three months. A reduction of seeding by 37.5% was recorded in 1991-1992. Although the activity of this weevil will help to reduce the high seed bank levels found in Australia, it seems unlikely that *R. conicus* on its own will control nodding thistle in Australia.

INTRODUCTION

Nodding thistle, *Carduus nutans*, naturally occurs in Europe, Siberia, Asia Minor and North Africa. It has become a weed in North and South America, New Zealand and Australia. Here it is a noxious weed that is widely distributed in the tableland regions of NSW, and sporadically present in elevated regions of southern Queensland, Victoria and Tasmania. Single infestations have been eradicated from South and Western Australia. Biological control of nodding thistle has been undertaken in Canada, USA, Argentina and New Zealand using the receptacle weevil, *Rhinocyllus conicus*, from the mid 1960's onwards (2). Releases of this weevil were first made in Australia in 1988 in the northern, central and southern tablelands of NSW, where the weevil is now established (11). This paper discusses seed destruction attributed to this weevil at Glencoe, NSW, and the effectiveness of the weevil in relation to the phenology of the thistle.

<u>Biology of the weevil</u>. The adult weevil is about 6 mm long, and emerges from diapause in mid spring, when it starts to feed on nodding thistle rosette leaves. Damage from this feeding is minimal. The female lays eggs on the first green flower buds (greens), which are usually heavily overloaded with eggs, such that although seed set is low, not many larvae survive to adulthood, due to overcrowding. The eggs are laid on the bracts surrounding the capitulum. Upon hatching the larvae burrow down into the receptacle, which they proceed to mine and prevent seed in the area above the damage from developing. Late instar larvae construct hard, black pupation cells inside the receptacle. The adult weevil emerges between 5-7 weeks after the eggs are laid, and seeks overwintering sites in the leaf litter. There is only one main generation a year. However, a very small proportion of the first adults to develop in the summer produce a second generation. Each female lays about 200 eggs, over a 6-8 week period (3).

<u>Biology of the thistle</u>. Nodding thistle biology has recently been reviewed by Popay and Medd (6). Only a brief outline is presented here with emphasis on the relevant aspects for biocontrol purposes. The seed bank in Australia can be as high as 12000/m^2, with the annual seed rain as high as 40000/m^2 (Woodburn and Cullen, unpublished data). In Europe the seed bank is very low, less than 60/m^2, with a seed rain of less than 250/m^2 (4). Seedlings quickly form prostrate rosettes, that can grow to over a meter in diameter. After vernalisation terminal capitula are formed, firstly on the main stem, and successively on the lower branches. The plant dies when seeding has finished.

METHODS

Assessment of seed rain. An unfenced experimental plot (25x25 m) was established at Glencoe in 1988 at the time of release of the weevil, in which ten randomly placed 0.25 m^2 permanent quadrats were positioned. In spring of each year the number of plants likely to flower was counted, and if more than 20 such plants were present, flowering data were recorded from them. In years when the number of flowering plants was low on the quadrats, or the quadrats were not characteristic of the plot as a whole, an area of the plot was randomly chosen, and its size increased until the number of flowering plants was sufficient to represent the plot as a whole.

Every fortnight throughout the season the diameter of each flowering capitulum on each plant selected as described above was recorded. The flowering stage was chosen because previous work on plant phenology had shown that 1): the flowering period of each capitulum was less than a fortnight, and hence it would only be measured once, and 2): the proportion of capitula passing from buds to matures during this interval is known, and hence a correction can be made for it (Woodburn and Cullen, unpublished data). A relationship between capitulum diameter of the flowering stage and seed production (Woodburn and Cullen, unpublished data) was used to predict the expected number of seed in each capitulum, and hence the expected seed rain/m^2 for each fortnight and cumulatively for each season.

Assessment of weevil damage. Samples of 50 randomly collected capitula, that had stopped producing flowers but had not started to shed seed, were collected at the same fortnightly intervals as above. At the beginning and end of the season when capitula were scarce, the area sampled was several hectares, but for most of the season the collection was made over less than a hectare. In the laboratory, the diameter of each capitula was measured, and counts were made of the numbers of eggs, larvae, pupae and/or adult weevils present. The number of mature seed set was also recorded. A modified relationship between the mature capitulum diameter and seed production was used to predict the expected number of seed in each capitulum. The effect of the weevil for each infested capitula was calculated as the difference between the observed and expected seed total. The impact in each sampling period was calculated from the proportion of heads attacked, and seeds destroyed, in each sample. These values were used to scale the expected seed rain/m^2, obtained from the fortnightly measurement of flowering capitula on the experimental plots, to produce the actual seed rain.

RESULTS AND DISCUSSION

R. conicus became established at Glencoe during the first year, 1988-89, and successfully overwintered (11), but numbers were not large enough for any impact on seed production to be assessed during 1989-90. The thistle population was monitored, however, and the results concerning the reproductive effort are presented in Table 1. Although the first formed capitula were the largest and therefore produced the most seed, these heads contribute very little to the overall seed rain, the bulk of which comes from large numbers of medium sized heads produced in mid season (Table 1).

In 1990-91 *R. conicus* attacked over 70% of the first heads produced in late November and early December (Table 2), averaging 19.4 and 8.1 eggs/attacked head respectively. The number of heads attacked dropped markedly from then, as did the number of eggs/head, until late in the season when there is evidence of the activity of a second generation. The reduction in seed set from the random samples was considerable in those heads attacked in November (73.5%) and moderate in those from April (21.4%). These peaks of activity, which represent the tail ends of the distribution of the production of capitula, had no impact on the estimated seasonal reduction in seed rain (16%), since none of the very small number of flowers present at these times occurred contributing to the density estimates of seeds/m² for the site.

Table 1. Phenology of flowering of nodding thistle at Glencoe, NSW during 1989-90

Date	22.11.89	13.12.89	27.12.89	9.1.90	30.1.90	7.2.90	21.2.90	7.3.90	Sum
Mean size of capitula ± s.e.	35	28 ± 1.3	24.5 ± 0.6	19.4 ± 0.4	15.4 ± 0.5	13.7 ± 0.4	14.8 ± 1.2	17.4 ± 0.6	
No. of capitula/m²	0.6	3.4	10.9	24	16	6.9	5.1	7.4	74.3
No. of seed/m²	309.9	1246.4	3101	4585.8	2104.3	741.3	646.3	1286.9	14021.9

Table 2. Proportion of capitula attacked by *R. conicus* at Glencoe, NSW during 1990-91

Date	22.11.90	12.12.90	24.12.91	4.1.91	18.1.91	29.1.91	12.2.91	26.2.91	12.3.91	3.4.91
Proportion attacked	0.71	0.77	0.13	n/a*	0.04	0.06	0.04	0.12	0.1	0.22

* no sample taken.

In the following season, 1991-92, *R. conicus* activity commenced in early November and continued until May, although flowering on the experimental plot did not commence until mid December and ceased in mid April (Table 3). For nearly 2 months at the beginning of the season the majority of all capitula were attacked, and most of the seeds were destroyed. As in the previous year, the seed destruction documented in the first two samples had little impact on the estimated overall seed rain as they formed an insignificant proportion. There was only slight evidence of the activity of a second generation at the end of the season. This can be attributed to low larval survival in samples collected before the end of December. From then on numbers of eggs/infested head dropped to a level where survival from egg to adult approached expected levels of around 50%. The overall effect of *R. conicus* activity for 1991-92 was a reduction of 35.7% in the total seed rain.

Table 3. Pattern of capitula disTribution, *R. conicus* lctivity and seed destruction at Glencoe, NSW during 1991-92.

Date (d.m)	5.11	30.11	10.12	17.12	31.12	14.1	28.1	11.2	7.3	24.3	12.4	16.5
no. heads/m²ᵃ			0.03	0.16	0.47	1.22	1.28	0.75	0.50	1.22	0.25	
prop of sample inf.ᵇ	1.0	1.0	1.0	1.0	0.98	0.35	0.44	0.11	0.02	0.02	0.0	0.02
eggs/inf. head	108.1	77.5	77.6	47.8	18.3	25.9	26.2	3.6	2.0	1.0	0.0	1.0
prop seed destroyed	1.0	1.0	1.0	0.98	0.98	0.48	0.26	0.06	0.01	0.003	0.0	0.005
actual seed set/m²			0	1.5	3.0	165.2	229.0	138.9	79.5	176.7	26.4	
expected seed set/m²			9.9	65.5	143.0	318.8	307.5	148.0	80.1	177.3	26.4	

[a] includes only capitula flowering on the experimental plot

[b] prop. = proportion, inf. = infested

The maximum level of seed loss recorded in Canada, 15 years after release of the weevil, was 50% (3). This was sufficient to control nodding thistle populations (3). In New Zealand, after a similar time lapse, the maximum level recorded was 40%, which was insufficient to control the thistle (4). Although the data reported here were collected only 3-4 years after release, it is unlikely that the level of reduction will continue to rise substantially. There are already high levels of attack and large numbers of insects/head resulting in nigh on total seed destruction for most of the period over which the weevil is active. The peak of capitulum production, however, escapes attack (Table 3). Nodding thistle in Australia and New Zealand grows more vigorously than it does in the northern hemisphere, which is in part a reflection of the longer growing season in the southern hemisphere. In 1988-89 plants at Glencoe produced an average of 14.2 capitula (range 1-60) over a 4 month period; at Kybeyan, NSW, 23.3 capitula were produced (range 1-87) over a 5 month period (Woodburn and Cullen, unpublished data). In Europe, plants averaged 6.4 capitula (4) over a 3 month period (A.W. Sheppard, unpublished data), and in Virginia, USA, the average number of green bud stage was estimated at 7.0, also over a three month period (5). In Europe attack by the weevil is restricted to the first two of the three month long flowering period, during which time 90% of the annual seed rain is produced (A.W. Sheppard, unpublished data), with a similar situation occurring in North America (5). In Australia the activity of the weevil is restricted to the first portion of the reproductive stage of the thistle, with the bulk of seeding occurring after weevil activity has ceased (Table 3). Although *R. conicus* has an impact on seed reduction, and will help to decrease the very high level of seeds in the seed bank (11) when compared to levels in European banks (7), it seems most unlikely that it will achieve control of nodding thistle here on its own. In order to augment the seed destruction already caused by the weevil, the seed fly, *Urophora solstitialis*, was released in 1991 (9). This fly, which due to its ability to undergo a second generation is potentially capable of reducing seeding in all capitula produced, is now established (10).

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INSECTS AND DISEASES OF FIREWEED, *SENECIO MADAGASCARIENSIS*, AND THE CLOSELY RELATED *SENECIO LAUTUS* COMPLEX

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Summary. Fireweed, *Senecio madagascariensis*, is an exotic species from Madagascar and South Africa. *S. madagascariensis* has become a major weed of pastures in eastern Australia. Field studies are currently under way in Australia to determine the insects and diseases found on *S. madagascariensis* and the closely related *S. lautus* complex in an effort to determine whether naturally occurring agents discriminate between these species. Most insects and diseases that occur on *S. madagascariensis* also occur on *S. lautus*. In excess of 70 species of insects and two rusts have been recorded on *Senecio* spp. to date.

INTRODUCTION

Fireweed, *Senecio madagascariensis* Poiret, is an exotic species which is native to Madagascar and South Africa. *S. madagascariensis* has become an important weed of pastures in eastern Australia where it covers hundreds of thousands of hectares. It was first recorded in the lower Hunter Valley in 1918 and has since spread throughout coastal regions of New South Wales, into parts of the Northern Tablelands and the Western Slopes, and into south-eastern Queensland (4). *S. madagascariensis* has the potential to continue to spread within and around its present limits of distribution, but is unlikely to cause serious problems elsewhere in Australia (6).

The cost of *S. madagascariensis* to the agricultural community is estimated to be in excess of $2 million per annum (L. Smith, pers. comm.). These losses are made up of decreased pasture production due to plant competition and reductions in growth rates or death of cattle and horses caused by pyrrolizidine alkaloids occurring in the plant (4).

Present methods of control include spraying with herbicides, mowing, hand weeding, competitive pastures and grazing by goats and sheep. However, the plant produces vast quantities of seed which germinate over a long period of time so control practices must be repeated at regular intervals.

There are many gaps in our knowledge of the ecology of *Senecio* spp. These include plant taxonomy, distribution and ecology, interactions between plant species, and the ecology and distribution of naturally occurring insects and diseases on *Senecio* spp. The Dairy Research and Development Corporation recently funded a three year co-operative research program between the Weed Ecology Unit at Sydney University and NSW Agriculture to study these aspects.

PLANT TAXONOMY

Correct identification of plant species is important in any form of control strategy. Because *S. madagascariensis* is similar to the native *Senecio lautus* Forster f. ex Willd. complex it is important to differentiate between the two species. This is especially important since members of the *S. lautus* complex are essentially non-weedy (5). The taxonomy of *S. madagascariensis* and the *S. lautus* complex is unclear at present. Four subspecies of the *S. lautus* complex have been recognised (1). However, *S. madagascariensis* was not recognised as a separate species and herbarium specimens indicate its inclusion in *S. lautus* aff. ssp. *lanceolatus* (5). Subsequent taxonomic studies (3) made it possible to differentiate between these two species. Current indications are that there may be more than four subspecies in the *S. lautus* complex.

INSECTS AND PATHOGENS ON *SENECIO* SPP.

Surveys in Madagascar (2) have found a variety of insects feeding on *S. madagascariensis*. Two of these insects, a stem and tip boring moth, *Lobesia* sp. (Lepidoptera: Tortricidae) and a flower feeding moth, *Phycitoides* sp. (Lepidoptera: Pyralidae) have been imported as potential biological control agents. Since mid 1990, The Alan Fletcher Research Station, Department of Lands, Queensland has been conducting quarantine host specificity studies on *Lobesia* sp. and *Phycitoides* sp. These studies are proceeding slowly, supported by a three year Meat Research Council grant. While severely damaging *S. madagascariensis*, these insects also damage the native *S. lautus* complex.

Australian field studies are currently under way to determine insects and diseases found on *S. madagascariensis* and the *S. lautus* complex in an effort to determine whether naturally occurring agents discriminate between these species. Most insects and diseases which occur on *S. madagascariensis* also occur on *S. lautus*. In excess of 70 species of insects, and two rusts have been recorded on *Senecio* spp. to date.

The most common insects include a leaf feeding beetle, *Chalcolampra* sp. (Coleoptera: Chrysomelidae); two moths, the leaf feeding magpie moth, *Nyctemera amica* (White) (Lepidoptera: Arctiidae) and blue stem borer, *Patagoniodes farinaria* (Turner) (Lepidoptera: Pyralidae) and two seed head feeding bugs, *Nysius clevelandensis* Evans and *Nysius vinitor* Bergroth (Hemiptera: Lygaeidae). A stem mining fly, *Melanagromyza seneciophila* Spencer (Diptera: Agromyzidae); a leaf mining fly, *Phytomyza syngenesiae* (Hardy) (Diptera: Agromyzidae) and two species of gall forming flies, *Sphenella ruficeps* (Macquart) (Diptera: Tephritidae) which forms galls in flower heads and *Trupanea* sp. (Diptera: Tephritidae) which forms galls in stems and flower heads, are also commonly found. The larvae of *Chalcolampra* sp. and *N. amica* can cause significant defoliation of *Senecio* spp. Larvae of *P. farinaria* ringbark stems and may kill many plants. The two rusts found on *Senecio* spp. are *Puccinia lagenophorae* Cooke and *Albugo tragopogonis* (DC.) S. F. Gray.

DISCUSSION

The studies in Madagascar (2) found two *Nysius* spp. feeding on seed heads of *S. madagascariensis*. Similarly, Australia has two *Nysius* species which feed on seed heads. The flower head feeding fly, *Sphenella marginata* (L.), was also found in Madagascar (2). There is some conjecture whether this is a different species to *S. ruficeps* (P. Cranston, pers. comm.), which was identified in this study. Many of the Australian insects found so far appear to be specific to *Senecio* spp. although generalist feeders such as some Lepidoptera, the *Nysius* spp. and the leaf mining fly, *P. syngenesiae*, were also found. *P. syngenesiae* feeds mainly on Asteraceae (7) while the others mentioned feed on a wide range of species in a number of families. In excess of 40 species of Hymenoptera have also been found so far during this study. Their role is unclear at present. Many of these are probably parasitoids of other insects found although some could be gall formers.

The taxonomic similarity between *S. madagascariensis* and the *S. lautus* complex is paralleled by the similarity in insect and disease species occurring on these plants. If imported biological control agents show a similar lack of discrimination, there will be a conflict of interest between biological control of *S. madagascariensis* and the desire to prevent damage to native *Senecio* species. The release of these imported agents may therefore not be approved by the Australian Quarantine Inspection Service and the Australian National Parks and Wildlife Service.

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A RENEWED ATTEMPT AT THE BIOLOGICAL CONTROL OF *LANTANA CAMARA*

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Summary. The Queensland Department of Lands has renewed its program to find suitable biological control agents for lantana (*Lantana camara*). Two insect species (*Charidotis pygmaea* and *Pyramidobela* sp.) have recently been released and four others (*Cremastobombycia lantanella*, *Aerenicopsis championi*, *Aconophora compressa* and *Adfalconia* sp.) are being evaluated in quarantine at the Alan Fletcher Research Station. The pathogen *Prospodium tuberculatum* is being evaluated in the United Kingdom and further introductions of both insects and pathogens are planned.

INTRODUCTION

Lantana, *Lantana camara*, was the first weed to be subjected to classical biological control. Its natural enemies were collected in Mexico in 1902 by Koebele who shipped 23 insect species to Hawaii. Many died during the long sea voyage but eight species were established (9). Attempts to control it biologically have been made in 25 countries using 35 different insect species collected from the Americas. The number of species released in any one country have ranged from one in several countries to 22 in Australia (8).

The successful establishment of these insect species has been erratic and difficult to predict, probably more so than in any other biological control project. The reason for this is that the name *Lantana camara* is used for a wide complex of plants including weedy forms which may be separate species or varieties (2). *L. camara sensu lato* is a man made polyploid complex developed in Europe over three centuries by horticulturalists from material collected in the New World (11). The complex contains many colour forms differing in their general morphology, chemistry, toxicity and ecology. Introduced insects have distinct preferences for one or more varieties.

This varietal problem was not recognized in early biocontrol programs and Haseler in 1963 recognized only four lantana varieties naturalized in eastern Australia (7). Smith and Smith (10) however, in a later taxonomic study list 29 different taxa as being naturalized in this region. *L. camara sensu stricto* does not occur in Australia (10).

Previous attempts to obtain biological control of lantana have been largely unsuccessful and it remains a serious to very serious weed throughout tropical and sub tropical regions of the world. The Queensland Department of Lands has thus reactivated its overseas exploration program to find suitable control agents.

CURRENT STATUS IN AUSTRALIA

Australia's involvement with the biological control of lantana commenced in 1914 when the first group of four introduced insects were released. Since then a number of field exploration programs have been carried out with the most intense period of introduction and field releases occuring between 1965 and 1977 when 14 insect species were released.

Of the 22 insect species released onto lantana up until 1992, 14 have become established - 9 widely and 5 at localised sites (8). The combined result of all these introductions has ranged from partial to zero control. In the areas of partial control, the competitiveness of lantana has been markedly reduced. Lantana, however, still remains one of Australia's most serious weeds affecting almost 4 million hectares (1). In Queensland an estimated A$17 million is spent annually on its control (12) and because of this continuing problem, a renewed attempt has been made by the Queensland Department of Lands to find new control organisms and to reinvestigate insect species previously tried in other countries.

NEW RESEARCH PROGRAM

Insects. The exploration for candidate insect species has been centred on Mexico from where many lantana feeding insect species have been found in the past but for varying reasons have not been successfully utilized. Exploration has also been carried out in Brazil and Argentina looking particularly for insects that feed on both lantana and creeping lantana, *L. montevidensis*.

To date this has resulted in the introduction and release of two species and the introduction into quarantine for host specificity testing of another four. These are as follows:-

Pyramidobela sp. A small moth whose larvae feed on the undersides of lantana and creeping lantana leaves. The larva shelters within the protection of a silken tunnel emerging to feed on the surrounding leaf tissue. It was originally collected from Brazil where it is heavily parasitised. It was recently released in Queensland.

Charidotis pygmaea. A leaf feeding chrysomelid beetle was collected from lantana and creeping lantana in Brazil. It is well adapted to shady environments as well as to southern (cool) latitudes. Lantana in this type of environment in Australia is largely unattacked by previously introduced biological control agents and *C. pygmaea* could fill this niche. It has recently been released in Queensland.

Aerenicopsis championi. This stem boring cerambycid beetle was first identified as a potential control agent of lantana by Koebele in his exploration of Mexico in 1902. It was shipped to Hawaii by Koebele (9) and also by Krauss in 1955-56 when over 1000 beetles were shipped and released into the field (3) where it failed to become established. Mann (1954 unpublished report) thought it to be the best insect for lantana control that he had seen. Field collected larvae have now been shipped to Australia where host specificity testing will be carried out in quarantine.

Aconophora compressa. This stem sap sucking membracid bug is probably the same species found by Mann in Mexico in 1953 and identified as *A. marginata*. Mann regarded it as the most important insect found feeding on lantana stems causing considerable lengths to wither and die. A shipment of adults sent to Hawaii were not successfully reared (Mann 1954 unpublished report). Several shipments were sent to Australia in 1993 and these are now being successfully reared and host specificity testing has begun.

Adfalconia sp. A leaf sap sucking mirid bug capable of causing considerable damage to lantana was shipped to Australia in 1993. Cage rearing was unsuccessful even though adult bugs fed and oviposited. Neonate bugs failed to feed and died in the first instar. The failure of this insect is probably due to lantana varietal differences even though three of the more common Queensland varieties, common pink, Helidon White and oblong red were used.

Cremastobombycia lantanella. This leaf mining gracillarid moth was found in Mexico and southern Texas, USA, with at least four species of *Lantana* as natural hosts (Palmer 1992 unpublished report). It was one of the species collected by Koebele in 1902 and subsequently released and established in Hawaii (9) where it is now one of the suite of insects responsible for a considerable reduction in the abundance of lantana particularly in drought prone areas (4). Preliminary host testing has been completed in Mexico and it has recently been shipped to Australia where cage rearing in quarantine has commenced.

Pathogens. A new direction in the biological control of lantana has been taken with the exploration in Brazil for suitable lantana pathogens. Four species were found, two at altitudes of 300 m in southern Brazil - the rust *Prospodium tuberculatum* and the hyphomycete *Mycovellosiella lantanae* and two in the humid tropical areas of northern and central Brazil - the rust *Puccinia lantanae* and a disease with symptoms similar to that of the web blight fungi, *Ceratobasidium* (12).

The host specificity testing of *P. tuberculatum* has commenced at the International Institute of Biological Control in the United Kingdom.

DISCUSSION

As *Lantana camara* sensu lato is a man made polyploid complex, with no true country of origin and which invades diverse ecosystems in Australia and other countries, the standard classical biological control procedure of exploring for natural enemies in its country of origin and in climatically similar habitats is largely irrelevant, as are the agent selection procedures recommended by Harris (6), Goeden (5) and Wapshere (13).

After nine decades and numerous intensive overseas explorations for new insect control agents, host specificity is the only issue likely to affect the release of any new introductions. Their affinity for any of the Australian lantana varieties will only be determined after their introduction into quarantine in Australia. The basis for the selection of any new agent should be its host range restriction to the genus Lantana.

The selection of pathogens for host specificity testing is influenced by lingering doubts by many plant pathologists as to their safety. The autoecious rust *Prospodium tuberculatum* was selected on the basis of its restriction to the genus *Lantana* and also after initial testing had shown its pathogenicity to the "common pink" lantana variety (Evans, 1988 unpublished report), the most abundant form of lantana in south eastern Queensland and New South Wales (2).

It is too early to predict the outcome of current investigations but it is obvious from cage studies that the different varieties of lantana in Australia will greatly influence the results. The failure of a control agent in Australia however does not mean that it should not be tried in other countries with different ecosystems and lantana varieties.

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WEEDS IN NO-TILL FALLOWS IN NORTHERN NEW SOUTH WALES

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Summary. A survey after the 1989 wheat harvest showed that 50% of fallow paddocks in northern New South Wales had a weed problem. By February 1990 only 10% of paddocks were being sprayed with a herbicide to control weeds whereas over 80% had been cultivated. Weed assessments in 65 no-till paddocks identified almost 100 different weed species. The most important weeds were liverseed grass, native millet, common sowthistle, wireweed, and barnyard grasses. Black bindweed was a problem where atrazine had not been used whereas native millet was the most abundant species where atrazine had been applied.

INTRODUCTION

In northern New South Wales both summer and winter crops are usually sown following accumulation of soil moisture in a fallow. Weeds are controlled by tillage during the fallow period but this has the undesirable effect of removing stubble. The soils, especially on slopes, are prone to erosion (3). Farmers have the opportunity to retain more stubble using conservation tillage practices involving herbicides. But with less tillage and more reliance on herbicides, different weed species may become a more serious problem. For example, common sowthistle, *Sonchus oleraceus*, populations increased rapidly with use of no-tillage practices compared to stubble burning (1).

During summer fallows there are three major periods when weeds appear; weeds present at wheat harvest, those that germinate during summer, and weeds that germinate in autumn. Perennial weeds may be present all the time. In 1983-85, farmers identified the 10 most important summer weed species on northern NSW wheat farms as thornapples, *Datura* spp., Bathurst burr, *Xanthium spinosum*, barnyard grasses, *Echinochloa* spp., mintweed, *Salvia reflexa*, liverseed grass, *Urochloa panicoides*, Noogoora burr, *Xanthium occidentale*, summer grasses, *Panicum* spp., yellow vine, *Tribulus* spp., Johnsongrass, *Sorghum halepense*, and cowvine, *Ipomoea lonchophylla* (2).

Paddocks treated in the previous winter cereal crop with a residual herbicide such as chlorsulfuron may have fewer weeds after harvest. Information on which weeds currently are the most important during the fallow period and which other weeds may become a problem if not controlled, is limited. Weed control strategies can be improved with this knowledge and future changes in weed species monitored (5).

This survey was undertaken to identify fallow management practices being used after wheat harvest by farmers in northern NSW and how these influenced stubble retention and weed control, and which summer weeds were present in no-till fallows.

METHODS

Following the 1989 wheat harvest paddocks were randomly selected in the northern wheat belt bounded by Tamworth, Gunnedah, Narrabri, Moree, Goondiwindi, Warialda, and Manilla to record fallow management practices being used, and the severity of weed infestations. Some paddocks were included in more than one survey and observations were taken on 151, 134, 120 and 190 paddocks on 18 December, 8 January, 18 January and 20 February respectively. Weed counts were done in 65 no-till fallow paddocks sampled between wheat harvest in 1989 and March 1990. Only no-till paddocks were included as we were primarily interested in weeds of no-tillage systems. An inverse sampling method (2) was used. An area 1 by 100 m was sampled by starting 20 m from the edge of the paddock and moving diagonally or perpendicular to the paddock margin depending upon the paddock size. The direction was changed after each transect. Weeds were recorded by number and species but density data are not considered in this paper. Weed species located adjacent to, but not present in, the transects were recorded as traces. Some weeds were grouped for convenience or because it was difficult to separate some species. For example, medics, *Medicago* spp., and clovers, *Trifolium* spp., thornapples, fleabanes, *Conyza* spp., and *Tribulus* spp. One to five areas were sampled in each paddock depending upon uniformity of the weed infestation. Weed occurrence was calculated as the proportion of paddocks containing each species.

The 65 no-till paddocks were divided into six categories: nothing since harvest [14], not grazed and sprayed with glyphosate [7], not grazed and sprayed with atrazine and glyphosate [5], grazed and not sprayed [11], grazed and sprayed with glyphosate [12], and grazed and sprayed with atrazine and glyphosate [16].

RESULTS

Rainfall from November to March was variable but there was adequate moisture for weed germination. Spraying herbicides on weeds, with or without grazing, accounted for less than 20% of the paddocks (Table 1). Volunteer wheat, *Triticum aestivum*, was the most common weed in both cultivated and uncultivated paddocks during the survey period but was not included in the results. A weed problem was identified in approximately 50% of the paddocks over the sampling period and those with a serious weed problem varied from 5% in early January to 18% in February (Table 1). The most obvious weeds in the general survey were barnyard grasses and liverseed grass; prickly lettuce, *Lactuca serriola*, common sowthistle, spear thistle, *Cirsium vulgare*, wireweed, *Polygonum aviculare*, saffron thistle, *Carthamus lanatus*, and wild oats, *Avena* spp, were common in December; thistles, fleabane, prickly lettuce and wireweed in mid-January; and mintweed and native millet in mid-February. Grazing without spraying resulted in fallows that were weedier.

Where no herbicide was used there were 74 species in ungrazed wheat stubble and 64 in grazed stubble (Table 2). Weeds found in all six fallow systems were Australian bindweed, *Convolvulus erubescens*, barnyard grasses, liverseed grass, native millet, fleabanes and common sowthistle. The number of species decreased where a herbicide had been used, particularly if both glyphosate and atrazine were included in the management program. Although the number of different weeds was reduced with herbicides, the proportion of paddocks with some of the species did not decrease. For example, common sowthistle occurred in over 50% of fallow paddocks irrespective of cultural practice. Liverseed grass was abundant in all paddocks except those which were not grazed but were sprayed with glyphosate. The proportion of paddocks with liverseed grass was greater in the grazed plus glyphosate category. The ungrazed sprayed with glyphosate practice selected black bindweed, *Fallopia convolvulus*, with all surveyed fields treated in this way infested. No black bindweed was present where atrazine had been used. Atrazine also reduced occurrence of barnyard grasses. There was a substantial increase in incidence of native millet with atrazine treatment and this was the most common weed in atrazine treated paddocks. Grazing reduced native millet populations where atrazine was used. Mintweed was on 50% of paddocks where no herbicide had been applied but was reduced to 25% in grazed plus glyphosate paddocks and was not present where atrazine had been used.

Table 1. The proportion of weedy paddocks in the general survey

	Time of sampling			
	18.12.89	8.1.90	18.1.90	20.2.90
		%		
Nothing	51	5	3	2
Cultivated	38	67	74	73
No-till, grazed	9	9	9	7
No-till, sprayed	1	19	13	17
Moderate weed problem	38	41	29	32
Severe weed problem	13	5	13	18
Number of paddocks	151	134	120	190

Table 2. Weeds with greater than 50% occurrence for each no-till cultural practice

Weed	Fallow - not grazed			Fallow - grazed		
	Nil	Gly[a]	Gly + Atr[b]	Nil	Gly	Gly + Atr
			%			
Barnyard grasses	57	57		82	67	
Bathurst burr			60			
Black bindweed		100				
Bladder ketmia	50	57				
Common sowthistle	57	71	80	55	67	75
Liverseed grass	64		80	82	75	69
Mintweed	50					
Native millet	50	57	100			100
Pigweed				64		
Wireweed						56
No. of paddocks	14	7	5	11	12	16
No. of different weeds	74	37	23	64	41	18

[a] Glyphosate
[b] Atrazine

DISCUSSION

Cultivation was the basis of fallow weed control on most farms (Table 1) but by the end of January stubble was virtually gone from two thirds of paddocks. Some farmers used weeds as cheap pasture. Cattle were not as efficient "weed eaters" as sheep but both graze selectively leaving thornapples, saffron thistle, St. Barnaby's thistle, *Centaurea solstitialis*, groundcherry, *Physalis* spp, Bathurst burr and camel melon, *Citrullus lanatus*. Many weeds suppressed by animals removing the tops, regenerated after stock were removed. More successful weed control was achieved where sheep grazed escapes after spraying rather than spraying to control weeds after grazing. We could not assess if grazing commenced before spraying or if farmers who integrated grazing into their management program were less timely applying herbicides.

A feature of the summer rainfall wheat region is that there are many weed species capable of invading and expanding into both fallows and crops. Over 100 species were found in the December to February period of this study. The climate provides an environment that allows weeds to be a problem at any time during the year. This places pressure on both herbicide selection and timing application.

The initial impact of herbicides was with selective in-crop weed control. More recently there has been increasing success in substituting tillage operations with spraying. In some situations weeds in the entire fallow period have been effectively and economically controlled without cultivations (4). When herbicides were used instead of cultivating the number of weed species in paddocks was reduced and some previously common species became less of a problem, for example atrazine reduced black bindweed, thornapples and barnyard grasses. But there is an increase in other species, for example perennial grasses, especially native millet which was widespread in the region and can be more difficult and more expensive to control.

The most significant change in wheat production in northern NSW in the last 10 years has been the acceptance of chlorsulfuron by farmers. Chlorsulfuron provides good control of many weeds which had increased during the 1970's with the use of herbicides such as 2,4-D, MCPA, dicamba, picloram and bromoxynil. Now we see emerging a new range of weeds which chlorsulfuron does not control, for example melons and common sowthistle. Glyphosate is the most widely used fallow herbicide but mixtures with other herbicides are used to improve control. These include 2,4-D, metsulfuron, triclopyr for melons, clopyralid for thistles, atrazine for mintweed and residual control, and fluroxypyr if drift with 2,4-D is a danger. Metsulfuron is often the second best alternative for many broadleaf weeds. Its broader spectrum of activity and price advantage has it currently the most popular option in mixtures with glyphosate.

A comparison with important weeds identified in 1985 (2) shows that liverseed grass, barnyard grasses, native millet, Australian bindweed, common sowthistle, fleabanes, and bladder ketmia, *Hibiscus trionum*, were more important in no-till fallows in 1990.

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STUDY ON WEED CONTROL IN NO-TILLAGE SUMMER CORN IN NORTH CHINA

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Summary. The importance of the weed control in summer corn under the no-tillage cropping system in north China are discussed. The main weed species in the crop for the region were investigated and soil-treated herbicides for control of these weeds were selected. A herbicide application method with reduced spraying volume and improved sprayers was developed and discussed.

INTRODUCTION

Rural labor is becoming less available in north China due to the rapid development of the rural industry and sideline production. In Beijing suburbs, about 85% of the labour force worked on farms in 1970's compared with 30% in 1990. Therefore, cropping techniques for saving labor were urgently needed for the development of agriculture, especially under the double-cropping system. For several years the techniques for no-tillage cropping have been rapidly developed and extended into summer corn in north China. The advantages of this are: (i) saving labor and energy; (ii) enabling seeding 3-7 days earlier; (iii) improving corn resistance to drought and waterlogging; and (iv) increasing corn yield by 500 kg/ha. Chemical weed control is one of the key parts of no-tillage cropping because of the weed problems and the large labor requirement of conventional weed control methods.

The objective of this work is to: (i) investigate the weed species and weed seed distribution in no-tillage summer corns; (ii) select suitable herbicides for controlling the weeds; and (iii) develop an efficient herbicide application method by improving the currently available application equipments.

METHODS

Weed species in summer corn were investigated for several times during the growing season of summer corn in north China where summer corn and winter wheat are annually cropped. Weed species were recorded and their interference levels were estimated and classified visually. Soil samples were collected from 0-5, 5-10, 10-20 cm depth in both no-till and traditionally flowed fields to investigate the weed seed distribution and content. Emerged weed seeds in the samples were determined by recording emerged seedlings at 25-28°C in a greenhouse.

Experiments were conducted in both parts and in the field to determine the inhibition level of atrazine on wheat. Fresh weight of leaves and roots were recorded.

Herbicides were selected by comparing their efficacy to the weeds and safety to the winter wheat crop.

Currently used spray equipment was improved by changing the nozzles to fit the application system. Pot and field experiments were conducted to compare the corn yield, the weed control percentage and the working efficiency between the reduced volume application method and the traditional application method.

RESULTS AND DISCUSSION

The investigation results showed that there were 134 species and 30 families of weeds in north China (Table 1). Common crabgrass (*Digitaria sanguinalis*) was the major weed species in corn.

Table 1. The main weed species in North China

Common name	Scientific name	Interference level[a]
Common crabgrass	*Digitaria sanguinalis*	+++
Green bristlegrass	*Setaria viridis*	++
Barnyard grass	*Echinochloa crusgalli*	+++
Goosegrass	*Eleusine indica*	++
Copper leaf	*Acalapha australis*	++
Redroot amaranth	*Amaranthus retroflexus*	+++
Purslane	*Portulaca oleracea*	++
Lambsquarters	*Chenopodium album*	++
Black nightshade	*Solanum nigrum*	++
Ivy glorybind	*Calystegia hederacea*	++
Rice galingale	*Cyperus iria*	++
Japanese hop	*Humulus scandens*	++
Yerbadetajo	*Eclipta prostrata*	++

[a] + = light; ++ = middle; +++ = heavy.

Weed seeds were mostly distributed in 0-10 cm in the soil in summer corns where the no-tillage was carried out continuously for several years (Table 2). This suggests that the soil treated herbicides might give a good control of the weeds in such a weedy field. Mixtures of atrazine+acetochlor, atrazine+butachlor or atrazine+alachlor were the ideal soil treated herbicides for controlling both of the grasses and broad-leaved weeds in no-tillage corns (Table 3). Atrazine was less effective against the dominating weed common crabgrass (Table 4). Moreover, atrazine would inhibit the growth of the rotation crop winter wheat if its residue in the soil after corn harvest is greater than 0.05 mg/kg (Table 5). The soil residue analysis results after corn showed that the atrazine residue was less than 0.05 mg/kg and no inhibition effect on the growth of winter wheat was observed when the herbicide mixtures atrazine+acetochlor, atrazine+butalchlor or atrazine+alachlor were applied at an atrazine dosage of 0.6 kg ai/ha. However, when atrazine was applied alone at a dosage of 1.2 kg/ha, its residue may cause injury to winter wheat in part of the fields because of its uneven distribution caused by incorrect application methods (Tables 3, 4 and 6). Results in Table 6 indicated that the weed control percentage was the same when using the low volume (60 L/ha) application method as for the normal volume (600 L/ha). However, the working efficiency was increased twofold when the low volume application method was used, and the water, energy, and labor for herbicide application could also be conserved.

Sufficient soil moisture is the premise for achieving good weed control efficiency with soil-treated herbicides. As meteorological reports over the past 40 years show there will be over 10 mm rainfall within 10 days of sowing summer corn in north China. Beside this, there are also irrigation systems in most areas of this region. These conditions promote the adoption of trial results of herbicide selection and the reduced spaying volume application method in no-tillage summer corn.

Table 2. Distribution and content (%) of the emerged weed seeds in the soil under the double cropping system by corn and wheat

Tillage methods	Tillage frequency	Soil depth (cm)		
		0-5	5-10	10-20
No-tillage	No-tillage only in summer corn	45	40	15
Plowed		31	11	58
No-tillage	No-tillage both in corn and wheat	76	20	4
Plowed		22	27	51

Table 3. Weed control percentage of different herbicide mixtures in summer corn

Herbicide mixture (kg ai/ha)	Common crabgrass	Annual broad-leaved	Total (%)	Corn yield	
				t/ha	ssr
Atrazine 1.2	73.1	96.7	80.1	7.92	a
Acetochlor 0.68	86.0	95.2	88.7	7.23	abc
Atrazine 0.60 + Acetochlor 0.73	92.5	99.2	94.5	7.93	a
Atrazine 0.60 + Butachlor 0.676	91.0	97.8	93.0	7.53	ab
Atrazine 0.60 + Alachlor 0.675	86.6	98.0	90.0	7.88	a
Hand weeding twice	93.5	100.0	95.4	7.70	ab
No-weeding	0.0	0.0	0.0	6.26	c

Table 4. Efficacy of different herbicides to weeds and corn in ppm

Herbicide	Common crabgrass ED90	Barnyard grass ED90	Red root amaranth ED90	Corn IC10
Atrazine	0.246	0.07	<0.06	>3.44
Acetochlor	<0.05	<0.05	0.08	1.03
Butachlor	0.10	0.11	>0.18	1.85
Alachlor	0.19	0.10	0.11	3.29

Table 5. Inhibition of atrazine to winter wheat.

Winter wheat	Concentration of atrazine (mg/kg)					
	0.00	0.01	0.03	0.05	0.10	0.15
Plant height (cm)	17.00	17.60	17.70	17.70	15.10	10.00
Inhibition rate (%)	0.00	-3.50	-4.10	0.00	11.20	41.20
Sten weight (g/5 plants)	3.27	3.33	3.38	3.27	1.62	0.78
Inhibition rate (%)	0.00	-1.80	-3.40	0.00	50.50	76.10
Root length (cm)	18.00	19.20	18.90	17.50	16.40	12.50
Inhibition rate (%)	0.00	-6.70	-5.00	2.70	8.90	30.50
Root weight (g/5 plants)	2.55	2.53	2.49	2.26	0.77	0.49
Inhibition rate (%)	0.00	8.60	2.40	11.40	69.80	80.80

Table 6. Weed control percentage and atrazine residue in soil after corn by different herbicide application and tillage methods

Tillage methods	Treatment (kg ai/ha)	Spraying volume (L/ha)	Residue (mg/kg)	Weed control (%)
mulched+no-tillage	Atrazine 0.6+Butachlor 0.56	600	0.025	90.7
	Atrazine 1.2	600	0.050	91.5
	Atrazine 1.8	600	0.065	95.7
unmulched+no-tillage	Atrazine 0.6+Butachlor 0.56	600	0.025	90.5
	Atrazine 1.2	600	0.045	84.9
	Atrazine 1.8	600	0.075	95.4
mulched+no-tilage	Atrazine 0.6+Butachlor 0.56	60	0.018	86.3
	Atrazine 1.2	60	0.035	93.6
	Atrazine 1.8	60	0.074	96.4
unmulched+no-tillage	Atrazine 0.6+Butachlor 0.56	60	0.024	82.4
	Atrazine 1.2	60	0.051	90.2
	Atrazine 1.8	60	0.087	96.7

Fan nozzles are normally used for applying herbicides in China but do not give a spraying volume as low as 60 L/ha. In order to get satisfactory weed control, a nozzle needed to be selected to which produced a low volume. After comparing betwwen nozzles even flat fan nozzles were selected and used to replace the former fan nozzles. A self-cleaning filter was developed and installed onto the boom sprayers to prevent the nozzles from blocking. As a result, the herbicide application method with reduced spraying volume and improved sprayers was rapidly extended in north China where winter wheat is grown after summer corns.

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EFFECTS OF FAT HEN AND BROAD-LEAVED DOCK ON CEREAL YIELDS

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Summary. Field experiments tested the effects of broad-leaved dock, ***Rumex obtusifolius***, and fat hen, *Chenopodium album*) seedlings on yields of wheat and barley, and of root regrowths of broad-leaved dock on yields of wheat. Fat hen seedlings reduced the yields of wheat and also of barley, but only when barley was sown at half the recommended rate. Dock seedlings had no effect on the yields of either wheat or barley. Regrowth from dock roots had more effect on wheat yields than seedlings of either species, confirming that dock roots surviving pre-sowing cultivation are a threat to cereals grown without herbicides.

INTRODUCTION

Increasing enthusiasm for cereals grown without herbicides and conventional fertilisers has renewed interest in the effects of weeds. At Flock House Agricultural Centre, on a small farm managed along 'organic' principles, broad-leaved dock has become a major problem, especially in the cropping phase of pasture/crop rotations, because of its regrowth from roots left in the soil after cultivation. Although docks look unsightly in crops, their effects on crop yields is unknown. This work was initiated to examine the effects of dock seedlings and root regrowth on cereal yields. Fat hen, a common cereal weed, whose effects on cereal yields have been reported previously (3,4), was included in the experiments for comparison.

METHODS

Three experiments were carried out, one testing the effects of seedlings of broad-leaved dock and fat hen on spring wheat sown in October 1990, the second testing the effects of the same weed seedlings on barley sown in early November 1991, and the third testing the effects of broad-leaved docks regrowing from roots on wheat sown in October 1992.

In the first two experiments, relatively weed-free crops were established by using a soil sterilant (dazomet) before planting. After the crop was drilled, weed seeds which had been collected the previous summer were evenly distributed by hand and lightly raked in. In Experiment 1, wheat (cv. Otane) was sown at standard rate, or standard + 20% and in Experiment 2, barley (cv. Fleet) was sown at standard rate, or at 50% of standard rate. Experimental design in both cases was 4 replicates of a split-split-plot, with 2 crop sowing rates as main plots, weed species (dock or fat hen) as sub-plots, and weed seed rate as sub-sub-plots. Sub-sub-plot size was 2.5x2.5 m. Crop plant density was assessed in late November each year and weed numbers counted in late November each year. Immediately before crop harvest, vegetation was harvested from a 0.5 m^2 quadrat typical of each sub-sub-plot in order to measure the dry matter of its component species. In the second experiment, with barley, weed plant numbers were again assessed at this time. Grain was harvested by hand from a 1 m^2 area at the centre of each sub-sub-plot.

In the third experiment, broad-leaved dock tap roots were planted at 5 densities (0, 2, 5, 10, 20/m^2) into 2 m^2 plots in 4 replicates, immediately after sowing wheat (cv Norseman). Grain was harvested by hand from the central 1 m^2 area of each plot.

RESULTS AND DISCUSSION

In the first experiment, wheat plant populations at the standard sowing rate were 197/m², and at the standard + 20% rate were 232/m². The rates at which weed seeds were sown, the numbers of seedlings of fat hen and broad-leaved dock which established, and the biomass of the sown weed species at crop harvest are shown in Fig. 1.

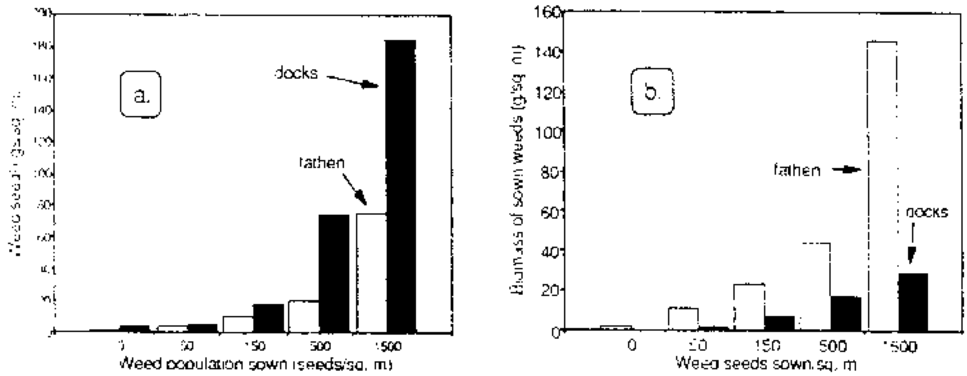

Figure 1. Experiment 1, wheat. Data averaged over both crop sowing rates and both fertiliser raason are no indication of the importance of weed biomass late in the season.

Dock seedlings established very well in this experiment, and fat hen seedlings rather less well. However, by crop harvest time, the dock plants were still quite small, whilst fat hen plants were much larger. Although not further discussed here, there were fewer weeds in November and lower weed biomass at harvest in the higher crop sowing rate. In spite of the soil sterilisation, a number of other species grew in the crop, especially large plants of chicory, *Cichorium intybus*, relicts of a previous crop. Partly because of this, analysis of variance of wheat yields did not show any effect of fat hen or dock. However, the correlation between fat hen biomass at harvest and wheat yield in each sub-sub-plot was very highly significant (r=0.33, 78 degrees of freedom, significant at p=0.01). There was no significant correlation between dock biomass and wheat yield, nor between fat hen or dock seedling numbers in November and wheat yield. This correlation could mean that in plots where the crop grew and yielded poorly, weeds grew better as a result. However, that the correlation with fat hen biomass was significant, while correlations with dock biomass or weed numbers were not, suggests that fat hen biomass adversely affected wheat yields, whilst docks had no affect. It also suggests that in determining the effects of weeds on crop yields, weed numbers early in the season are no indication of the importance of weed biomass late in the season.

In the second experiment, barley plant populations were 311/m² at the standard sowing rate and 150/m² at the 50% rate. Weed seed sowing rates, weed plant numbers in November and at harvest, and fat hen biomass at harvest are presented in Fig. 2.

More than twice as many weed seedlings established when the crop sowing rate was halved. Dock seedling establishment was poor in this experiment and at harvest dock plants were still small, but whether this was due to the greater competition offered by barley, or to seasonal effects, cannot be determined. Dock biomass at harvest was negligible. Growth of unsown weed species, principally scrambling fumitory, *Fumaria muralis*, again meant that analysis of variance did not show any effects of weeds on barley yields. The correlation between fat hen biomass at harvest and barley yields was significant in the 50% crop sowing rate (r=0.43, with 30 degrees of freedom, significant at p=0.05). The same correlation in the standard sowing rate was not significant. This again suggests that fat hen biomass at harvest affected barley yields, but only where the barley was sown at 50% of the standard sowing rate; at the standard crop sowing rate, fat hen had no effect.

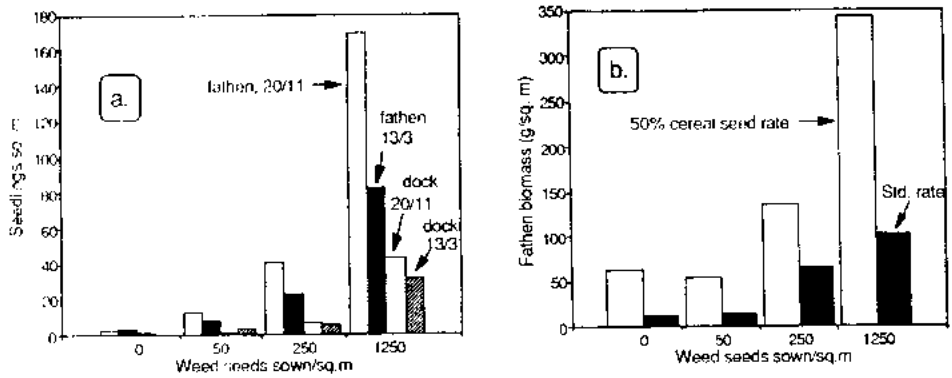

Figure 2. Experiment 2, barley. (a) Populations of sown weed species on 20 November and 13 March, averaged over both crop sowing rates. (b) Biomass of fat hen at crop harvest.

In the third experiment, regrowth from broad-leaved dock roots adversely affected wheat yields (Fig. 3). The best fit for the relationship was given when natural logarithms of mean wheat yield were plotted against planted dock root numbers. The correlation coefficient (0.98) was very highly significant (p=0.01).

As expected, fat hen was a more competitive weed of cereals than broad-leaved dock. Docks are not mentioned in the literature as weeds of cereals (e.g. 1). In barley, a more competitive crop than wheat (3), fat hen only reduced crop yields when the crop was sown at half the recommended rate. Increasing the density of barley diminished the competitive affect of weeds (2). Regrowth from the roots of broad-leaved dock reduced wheat yields, confirming that this species is more than an eyesore in cereal crops grown without herbicides. In wheat, each 100 g of fat hen dry matter/m^2 present at harvest reduced grain yields by 310 kg/ha, and in barley sown at half rate by 298 kg/ha. In wheat, each dock root/m^2 reduced grain yield by about 200 kg/ha.

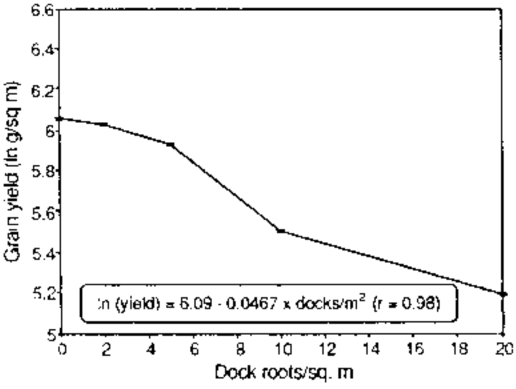

Figure 3. Experiment 3, wheat. Effect of transplanted broad-leaved dock roots on grain yield.

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THE BIOLOGY OF TUSSOCK SEDGE (*CAREX APPRESSA*) AND ITS CONTROL IN UNPLOUGHED LAND

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Summary. Tussock sedge seed germinated readily in a laboratory 5 months after collection and maintained viability for at least three years thereafter. Seedlings emerged from 0 to 40 mm depth in soil but not from 80 mm. Seedling growth in the 39 days after sowing seed was inferior to improved pasture species. Mature tussock sedge plants on non-arable land were killed by glyphosate but regeneration from seed in the soil threatens long term control because improved pasture species could not control them by competition (despite the comparatively slow growth of the sedge seedlings), because legumes were unable to establish in the wet environment inhabited by tussock sedge. Further research is necessary to find a practical method of controlling seedling regeneration of tussock sedge after mature plants have been killed by herbicide.

INTRODUCTION

In some regions of New South Wales (NSW) and Victoria tussock sedge (*Carex appressa* R. Br.), a native plant, has spread from swamps and drainage lines and replaced native and improved pastures on mid-slope areas. A heavy infestation can substantially reduce animal production because it is unpalatable to sheep and cattle and physically dominates the pasture causing shading and competition. Tussock sedge is difficult to control on arable land because its large leaf bases makes ploughing ineffective unless heavy implements are used. Although preliminary investigations have been made into the effects of herbicides on tussock sedge on non-arable land (J.B. Shovelton, pers. comm.; (2)) no research has been conducted into the associated biology of the plant. The prospect of tussock sedge becoming a weed in NSW prompted the following investigations into its biology and control.

METHODS

Germination. Seeds of tussock sedge were collected from Boorowa and Bigga NSW in late spring or summer (Table 1), stored in metal containers in a laboratory and germinated at annual intervals in petri dishes under constant fluorescent light (20 $\mu Em^2.s$) and temperatures of 15-25°C.

Emergence. Seeds collected from Bigga in December 1991 were sown at 0, 5, 10, 20, 40 and 80 mm depths in liberally watered clay loam soil (bulk density 1.16 g/cm^3; mean strength of soil surface 0.7 kg/cm^2) in July 1992 and emergence observed over 47 days at 25°C. On day 48 soil was washed off the underground parts of seedlings to measure the length of the stem and primary root at each depth.

Seedling growth. Growth of tussock sedge, subterranean clover cv. Karridale (*Trifolium subterraneum*), white clover cv. Haifa (*T. repens*), cocksfoot cv. Currie (*Dactylis glomerata*) and phalaris cv. Sirosa (*Phalaris aquatica*) was recorded in soil in pots in a glasshouse at 25°C for 39 days after sowing the seeds.

Control. The effect of herbicides and oversowing on the control of tussock sedge was ascertained near Bigga where the soil is derived from granite. The mature sedge plants were 1 m high and growing on a mid-slope area subject to free surface water in wet winters and springs. Plots were sprayed on March 13 and May 8, 1990 with glyphosate (Table 4) in 200, 500 and 1000 L/ha of water with 0.2% adjuvant Turbo®. The March treatments were oversprayed with glyphosate on May 8 1990 and all treatments surface-sown with seed of cocksfoot cv. Currie, phalaris cvs Australian and Sirosa, subterranean clover cv. Karridale and white clover cv. Haifa and topdressed with Mo superphosphate (300 kg/ha) on 14 May 1990. Good rain in summer 1989/90 (247 mm) and autumn 1990 (339 mm) ensured that there was adequate moisture for growth of tussock sedge at each time of spraying. The kill of tussock sedge was recorded on December 6 1991 and establishment and growth of sown species and re-infestation of seedling tussock sedge from winter 1990 till April 1993.

RESULTS AND DISCUSSION

Germination. Ripe seeds harvested in late spring or summer germinated readily in the laboratory 5 or 6 months later (Table 1). The germination of 3 out of 4 seed samples, collected in different years from 2 locations, did not decline over time; germination of the fourth sample declined in the second year (Table 1).

Germination to the radicle emergence stage took 9 days under the conditions imposed in these experiments which is slower than for phalaris and cocksfoot which took 4 days.

Table 1.
Germination (%) of tussock sedge seeds at annual intervals, examining different after-ripening periods (AP) in months

Collection date of seed	Germination in 45 days in May or June:					
	1990		1991		1992	
	%	(AP)	%	(AP)	%	(AP)
			Boorowa			
30 Nov 89	64	(4)	83	(18)	81	(31)
18 Dec 90			85	(5)	51	(18)
12 Dec 91					89	(6)
			Bigga			
1 Dec 89	86	(4)	89	(18)	84	(31)
22 Nov 90			90	(5)	86	(19)
8 Dec 91					92	(6)

Emergence. Increasing depth of sowing reduced percentage emergence of tussock sedge (Table 2). In general the time taken for emergence increased and growth rate decreased with increasing depth of sowing; the exception to this trend being the surface-sown seed (Table 2).

The method of emergence of tussock sedge was for the stem to grow from the seed to the soil surface where the buds for leaf and root growth developed. This resulted in increasing length of stem and decreasing length of primary root (from the seed) with increasing depth of sowing (Table 2). Seeds sown at 80 mm failed to emerge, the stem growing 44 mm towards the surface before dying.

Table 2.
Effect of depth of sowing of tussock sedge seeds on emergence and growth in the 47 days after sowing

Sowing depth (mm)	Emergence (%)	Mean time for emergence (days)	Mean height (mm)	Length of stem[b] (mm)	Length of primary root (mm)
Surface	100 a[a]	22 bc	76 b	0	70
5	77 b	17 a	90 a	5	68
10	41 c	19 ab	75 bc	11	41
20	29 cd	22 bc	65 cd	22	12
40	14 d	24 c	55 d	42	7
80	0 e	-	-	44	3

[a] Values in columns not followed by a common letter differ significantly ($P<0.05$).
[b] From seed to soil surface.

<u>Seedling growth</u>. Tussock sedge grew more slowly ($P<0.05$) than the other species tested (Table 3).

Table 3.
Growth of seedlings of tussock sedge and improved pasture species in 39 days after sowing

Species	Dry weight/plant (mg)
Subterranean clover	58.6a[a]
Phalaris	16.2b
Cocksfoot	10.5c
White clover	6.8d
Tussock sedge	1.3e

[a] Values not followed by a common letter differ significantly ($P<0.05$).

Control. The split applications of glyphosate (March and May) were more ($P<0.05$) effective in killing tussock sedge than single applications in May (Table 4). Rate of water carrier had no ($P<0.05$) effect of herbicide efficiency.

Good establishment of cocksfoot and phalaris and poor establishment of sown legumes occurred on all sprayed treatments in winter 1990. By late spring 1990 ground cover of cocksfoot, phalaris and volunteer species was 30% on the sprayed plots which was insufficient to control a heavy infestation of seedling tussock sedge. These seedlings died during the dry 1990/91 summer and autumn (172 mm rain). By December 1991 the mean ground cover of cocksfoot and phalaris on sprayed plots was 61% with no seedling tussock sedge. However in winter 1992 seedling sedge established from seed in the soil despite competition from sown species. By April 1993 the ground cover of seedling sedge was 9% and that of cocksfoot and phalaris 57%. During the period of the experiment sown legumes contributed less than 5% ground cover; phalaris was the dominant sown grass contributing 55% of the 57% total ground cover of sown grasses in April 1993.

Table 4.
Effect of glyphosate on percentage kill of tussock sedge, recorded on December 6, 1991; each treatment meaned for three rates of water carrier

Glyphosate (kg a.i./ha) applied on:			Kill
March 3, 1990		May 8, 1990	(%)
0.9	+	0.7	99.6a[*]
1.4	+	0.7	100.0a
1.8	+	0.7	100.0a
Nil		0.9	67.7c
Nil		1.4	91.7b
Nil		1.8	94.0b
Nil		Nil	3.0d

[*] Values not followed by a common letter differ significantly ($P<0.05$).

Conclusions. Despite good kills of tussock sedge with split applications of glyphosate in 1990, regeneration from seed in the soil threatens to undermine long term control. Because the seed remains viable for at least three years, regeneration from seed will be a constant threat unless seedlings can be killed by pasture competition soon after germination when their growth is slow compared to that of sown species. In the experiment on control of sedge, the sown grasses were unable to kill tussock sedge seedlings by competition. Generally legumes are relied upon to kill seedlings of grass weeds, e.g. serrated tussock (1), by excluding their light supply whilst the pasture is ungrazed. In the wet environment of the control experiment, subterranean and white clovers were unable to establish and thus could not provide the competition for light necessary to kill tussock sedge seedlings. Other legumes were tested in 1991 and 1992 with lotus cv. Maku (*Lotus pedunculatus*) proving most promising in 1992. Further research is necessary to investigate methods of controlling seedling regeneration of tussock sedge.

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SUPPRESSION OF WEED GROWTH DURING THE GERMINATION AND ESTABLISHMENT OF NATIVE GRASSES USED FOR REVEGETATION

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Summary. Effective revegetation of conservation areas and degraded sites with Australian native grassland species is often limited by the generally slow early growth of native grasses. Vigorous exotic grass and broadleaf weeds which are stimulated to germinate at the time of sowing are often major competitots. In this paper we evaluate the potential of several non-chemical methods for suppressing weed growth during the germination and establishment of wallaby grass, *Danthonia richardsonii*, and kangaroo grass, *Themeda triandra*: broadcasting seeds versus drilling them in rows; increasing the planting density above that which may normally be recommended for establishing a stable grassland community; applying phosphate fertiliser; and, adding to the seed mix a vigorous but short lived cover (or nurse) crop.

INTRODUCTION

Many of Australia's native grasses exhibit considerable tolerance of drought conditions and nutrient deficient soils (1,2,3). As a result of these adaptations, their perceived persistence, and a growing appreciation of their aesthetic qualities and conservation value, interest has increased over recent years in using them for sustainable grazing systems, soil conservation and amenity plantings. Research by the CSIRO's Division of Plant Industry in Canberra into the development and management of native grasses for use in revegetation programmes has targeted two species, namely the cool-season perennial, wallaby grass, *Danthonia richardsonii* (5), and the summer-growing perennial, kangaroo grass, *Themeda triandra* (syn. *Themeda australis*) (7).

Effective revegetation with Australian native grassland species is often limited by the generally slow early growth of native grasses in combination with competition from more vigorous exotic grass and broadleaf weeds which are stimulated to germinate at the time of sowing. Kangaroo and wallaby grass seedlings, for example, produce less biomass over the first 2 to 3 months following germination compared with agricultural species used for revegetation such as tall fescue, *Festuca arundinacea,* and perennial ryegrass, *Lolium perenne* (Reyenga, unpublished data). The presence of weeds can significantly reduce the emergence and biomass production of wallaby grass and, to a lesser extent, kangaroo grass (4). There has been little success in the selection of post-emergent herbicides that are able to control grass weeds without detrimental effects on the native grasses (6). A greater level of weed control has been achieved with residual pre-emergent herbicides (4,6) and manipulations of the site, seedbed, and seed mix (8). Two experiments were conducted to evaluate the effectiveness of various sowing methods and planting densities, and the presence or absence of a cover crop on the suppression of weed growth during the germination and establishment of wallaby grass and kangaroo grass. The effect of phosphate fertiliser on weed growth was also measured in the second experiment. Our hypothesis was that by manipulating these factors the competitiveness of the sown native grasses could be improved relative to the volunteer species.

METHODS

<u>Experiment 1</u>. The first experiment with wallaby grass was conducted at the ACT Parks and Conservation Service field site at Yarralumla, ACT, on a low fertility sandy loam which had been cultivated and sown down to native grasses 6 years earlier but which, becuase of regular mowings, had become overgrown with weeds, particularly flat weed, *Hypochoeris radicata*. The experiment had a 2x2x2 factorial design with three randomised complete blocks, and a plot size of 1 m^2. The treatments were as follows:

Factor 1 — two planting methods, broadcasting versus drilling seeds in rows 15 cm apart.
Factor 2 — two planting densities, low (1000 germinable seeds/m^2) and high (3000 germinable seeds/m^2).
Factor 3 — presence (+) or absence (-) of a cover crop of cereal rye, *Secale cereale*, sown at 100 germinable seeds/m^2 either broadcast or in rows with the wallaby grass.

The site was rotary hoed and raked to remove excessive vegetative matter prior to seeds of wallaby grass and cereal rye being either drilled or broadcast and covered with soil to a depth of 1 cm on 12 March 1993. The plots were initially irrigated to promote germination. Emergence counts of sown and volunteer species were taken 5 weeks after sowing in two fixed 30x30 cm subplots. Weed and grass biomass will be harvested in mid September from the same subplots.

<u>Experiment 2</u>. A second experiment, which had the same treatments and design as Experiment 1, but sown to kangaroo grass rather than wallaby grass, was begun in a heated glasshouse on 5 May 1993. Being a warm season species, kangaroo grass would not have grown well in the field during the cool winter months. Seeds were sown at a depth of 1 cm into 28x57.5x7.5 cm wooden flats filled with soil collected from the site of Experiment 1. An additional fourth treatment factor was included in this experiment which involved either the application of superphosphate (with the seeds) at a rate of 250 kg/ha (9.1% P) to all low sowing density treatment combinations or the absence of application. Two additional control treatments were also included to determine to what extent the weeds and kangaroo grass were being suppressed in absolute terms in each of the other treatments. In the first control, weeds were allowed to grow without competition from grass or cover crop. In the second control, sown using the broadcast method at a high density without a cover crop, all weeds were removed regularly by hand. It was hypothesised that this treatment combination would produce the maximum biomass of a kangaroo grass because of its greater utilisation of soil resources. Emergence counts of sown and volunteer species were taken 5 weeks after sowing in fixed 10x57.5 cm subplots. Weed and grass biomass will be harvested in August 1993.

RESULTS AND DISCUSSION

These experiments are still in progress and so only the emergence data from Experiment 1 are presented here (Table 1). The combined emergence of volunteer broadleaf weeds (principally flat weed and wireweed, *Polygonum* sp.) and grasses (*Digitaria* sp. and *Eleusine* sp.) was high in this experiment (greater than wallaby grass in low density treatments (Table 1)) and demonstrates one of the major problems faced when establishing native grasses from seed. Neither the percentage germination of wallaby grass, the number of grass weeds nor the total number of weeds that emerged after 5 weeks was significantly altered by either the sowing rate of wallaby grass, sowing method or the presence of a cover crop ($P>0.05$). Although there were no significant differences in the germination of cereal rye between treatments, germination percentages greater than 100% were common, due to the subsampling procedure and uneven distribution within the plots. The number of broadleaf weeds was significantly reduced by the presence of the cover crop ($F=4.94$ d.f.$=1,14$ $P=0.043$), possibly because the cereal rye was able to germinate within several days (7) and reduce the availability of resources such as moisture and light to the weeds. This conclusion is tentative however, given that the emergence of the grass weeds was not affected. All treatments in this experiment would appear to have given an establishment density in excess of practical requirements but weed biomass measurements should indicate if the higher density sowings offer an advantage for early weed control.

Table 1. Mean emergence counts for wallaby grass, cereal rye, and grass and broadleaf weeds per m^2 5 weeks after sowing. Significant differences are indicated in the text

Group	Grass sowing density	Broadcast		Drilled	
	Cover crop	-	+	-	+
Wallaby grass	High	1645	1332	1388	1835
	Low	723	709	524	566
% Emergence	High	54.7	44.4	46.2	60.5
	Low	72.3	70.9	52.4	56.6
Cereal rye	High	-	127.7	-	105.5
	Low	-	122.1	-	105.4
Grass weeds	High	786	725	934	1153
	Low	777	777	685	653
Broadleaf weeds	High	307	205	353	383
	Low	512	292	398	339
Total weeds	High	1093	931	1288	1536
	Low	1289	1069	1082	992

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THE USE OF FLUROXYPYR FOR BROAD-LEAVED WEED CONTROL IN SORGHUM IN SOUTHERN QUEENSLAND AND NORTHERN NEW SOUTH WALES.

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Summary. Following an extensive series of experiments, fluroxypyr is now registered for the control of noogoora burr, *Xanthium pungens*, pigweed, *Portulaca oleracea*, wild gooseberry, *Physalis minima*, annual ground cherry, *Physalis angulata*, and thornapples, *Datura* spp., at 0.1-0.15 kg acid equivalent/ha. Optimum control was achieved when fluroxypyr was applied to actively growing weeds up to and including the 6 leaf stage. The combination of fluroxypyr (0.1-0.15 kg/ha) and atrazine (1.0 kg active ingredient/ha) broadened the spectrum of broad-leaved weeds controlled with no effect on sorghum yield. Plant back periods ranging from 7 to 28 days after spraying were established for wheat, barley, sorghum, sunflower, chickpea, maize, soybean and cotton.

INTRODUCTION

Fluroxypyr (1-methyl heptyl ester) is a readily translocated herbicide, exhibiting a high degree of activity with post-emergent foliar application to a range of broad-leaved weeds. In susceptible species, it induces characteristic auxin-type responses, frequently within a few hours of application. The activity of fluroxypyr has been well documented (2,3,4,5). Results indicated that fluroxypyr is most effective when the weeds to be controlled are growing actively, with conditions favourable for plant growth. The potential use of fluroxypyr with glyphosate to control a broad range of weeds in fallow has required plant-back studies to be conducted to determine safe plant-back intervals to major crops following application of fluroxypyr.

This paper reports the results of field experiments conducted between 1983 and 1992, in southern Queensland and northern NSW to:

1. determine activity on a range of broad-leaved weeds with and without atrazine;
2. establish plant-back times for major rotational crops; and
3. determine tolerance of the major sorghum varieties.

METHODS

Formulations of fluroxypyr methyl heptyl ester contained an adequate level of adjuvant and no additional adjuvants were used in the experiments. Experiments were randomised complete block design with three or four replicates. The treatments were applied with an Azo propane precision sprayer delivering 80-120 L/ha, using 110 degree flat fan nozzles. Weed control was assessed visually 4-6 weeks after application using a 0-100 percent rating scale, where 0 = no control and 100 = complete control. Grain yields were also obtained. The data for each weed is presented as the mean % control where trials were conducted over several seasons.

RESULTS AND DISCUSSION

Weed control. Results in table 1 show fluroxypyr at 0.105 kg/ha gave acceptable control (>85%) of noogoora burr, pigweed, annual ground cherry and wild gooseberry, which were actively growing and up to the 6 leaf stage.

On noogoora burr, pigweed and *Physalis* spp. more than 6 leaf and thornapple up to the 8 leaf stage, 0.15 kg/ha was required. Fluroxypyr at 0.21 kg/ha gave the best control of volunteer sunflower, *Helianthus annus*, up to 45 cm high.

Fluroxypyr at 0.3 kg/ha or 0.15 kg/ha plus atrazine at 1.0 kg/ha was required to control caltrop, *Tribulus terrestris*. This mixture of fluroxypyr and atrazine gave the best control of the range of weeds shown in table 1.

Table 1. Percent control of broad-leaved weeds with fluroxypyr, with and without atrazine, applied post-emergence in grain sorghum in Southern Queensland and Northern NSW, 1983-91.

Weed	Height diameter (cm)	Fluroxypyr (kg/ha)					Combination (kg/ha)
		0.075	0.105	0.15	0.21	0.3	0.15+1.0
Xanthium	<20	77 (7)*	98 (5)	100 (7)	100 (7)	99 (7)	
pungens	20-50	26 (2)	87 (1)	95 (3)	95 (2)	100 (3)	96 (5)
Datura	<15	87 (6)	80 (6)	94 (8)	-	97 (5)	
spp.	15-30	82 (3)	88 (3)	88 (5)	92 (2)	89 (4)	97 (7)
Physalis	<15	100 (2)	100 (2)	100 (4)	100 (2)	100 (4)	
spp.	15-230	98 (2)	87 (3)	98 (4)	100 (4)	100 (2)	100 (5)
Portulaca	10	95 (2)	100 (3)	100 (4)	99 (3)	100 (2)	
oleracea	10-30	84 (3)	92 (3)	97 (3)	98 (2)	100 (1)	-
Tribulus	<15	27 (6)	59 (5)	78 (6)	75 (7)	80 (5)	
terrestris	15-40	45 (2)	34 (3)	62 (6)	78 (9)	82 (9)	97 (7)
Nicandra physalodes	30	-	-	100 (2)	10 (2)	-	100 (2)
Anoda cristata	5-8	-	58 (1)	71 (1)	-	-	100 (1)
Helianthus annus	15-45	-	-	60 (2)	97 (3)	98 (4)	60 (2)
Hibiscus trionum	4-28	-	18 (5)	22 (8)	28 (8)	37 (7)	85 (8)
Salvia reflexa	12-15	-	30 (1)	75 (2)	80 (2)	75 (2)	85 (1)
Amaranthus cruentus	8-20	-	20 (3)	29 (4)	43 (4)	58 (4)	86 (5)
Amaranthus macrocarpus	8-25	-	0 (4)	4 (9)	13 (9)	23 (10)	94 (9)
Sesbania cannabina	5-12	-	-	81 (2)	-	96 (2)	100 (2)
Commelina benghalensis	3-6	-	61 (1)	71 (1)	-	-	100 (1)

* ( ) = number of trials.

Plant back studies. In the 1990/91 and 1991/92 experiments, a period of seven days after application was used to simulate the time required for fluroxypyr to effect weed control before planting. Wheat, barley, sorghum, sunflower, chickpea and maize were the least sensitive crops showing no visual effects when planted 7 days after application of fluroxypyr at 0.075-0.3 kg/ha. Soybean was slightly sensitive requiring a 14 day plant-back period for fluroxypyr over 0.15 kg/ha and cotton, the most sensitive, requiring a 14 day plant-back period for fluroxypyr 0.075-0.15 kg/ha, and 28 days for fluroxypyr at 0.3 kg/ha as shown in table 2.

Table 2. The plant-back period (days) required for a number of crops following application of fluroxypyr to a black clay soil, northern NSW, 1990-92

Crop	Rate of fluroxypyr (kg/ha)		
	0.075	0.15	0.3
Wheat	7	7	7
Barley	7	7	7
Sorghum	7	7	7
Sunflower	7	7	7
Maize	7	7	7
Chickpea	7	7	7
Soybean	7	7	14
Cotton	14	14	28

Crop tolerance. The yield results in table 3 show fluroxypyr formulations applied to 4-6 leaf sorghum grown under weed free conditions did not cause a significant reduction in yield.

Table 3. Yield response (t/ha) of two weed free sorghum varieties following the application of fluroxypyr at two growth stages, Breeza, NSW, 1990/91.

Treatment	Rate (kg/ha)	DeKalb 37		Goldfield	
		4 leaf	6 leaf	4 leaf	6 leaf
Fluroxypyr[a]	0.15	1.9	2.0	1.0	0.9
Fluroxypyr[a]	0.3	1.9	2.4	1.2	0.9
Fluroxypyr[b]	0.15	1.8	1.9	1.0	0.8
Fluroxypyr[b]	0.3	1.8	2.0	1.0	0.8
Fluroxypyr[a]	0.15	2.3	2.5	1.1	0.8
+ atrazine	1.0				
Untreated	-	1.8	1.8	1.0	0.8
	l.s.d.	0.4	0.5	0.3	0.2
	c.v. (%)	13	17	19	16

[a] = 200 g/L formulation
[b] = 300 g/L formulation

Results from the 1991 Agrisearch weed free sorghum variety crop tolerance screen (1) showed across the sixteen sorghum varieties screened, that a significant increase in yield occurred when treated with fluroxypyr at 0.15 and 0.3 kg/ha compared to the standard, 2,4-D (dimethylamine salt) at 1.05 kg/ha. There was no difference between the untreated controls and fluroxypyr applications. Overall, no effects on crop vigour were seen or measured following the application of fluroxypyr.

Conclusion. Fluroxypyr at 0.105- 0.15 kg/ha gave excellent control of noogoora burr, pigweed, thornapple and *Physalis* spp. up to the 6 leaf growth stage. Fluroxypyr at 0.15 kg/ha plus atrazine at 1.0 kg/ha provided excellent control of all broad-leaved weeds present in the sorghum trials, with no effect on the yield of sorghum in a weed free environment.

At the use rate of 0.105-0.15 kg/ha, an interval of 7 days after application of fluroxypyr was required prior to planting wheat, barley, chickpea, sorghum, maize, sunflower and soybean. An interval of 14 days after application of fluroxypyr at 0.105-0.15 kg/ha was required for the safe planting of cotton.

Selectivity of fluroxypyr at 0.15-0.3 kg/ha to sorghum, applied at the 4-6 leaf growth stage, was excellent, with no yield reduction compared to the untreated.

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INFLUENCE OF POST-EMERGENCE APPLICATION TIMING ON RHIZOME JOHNSONGRASS CONTROL IN CORN WITH NICOSULFURON AND PRIMISULFURON

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Summary. The influence of application timing on nicosulfuron and primisulfuron activity in rhizome johnsongrass, *Sorghum halepense*, was examined in a naturally infested corn field in north-eastern Kansas, USA. Herbicide treatments included single applications at 0.5, 0.75, and 1.0X rates (1.0X = 35 and 40 g/ha for nicosulfuron and primisulfuron, respectively) and split applications at 0.5 plus 0.5X and 0.75 plus 0.25X rates. Split applications provided more rhizome johnsongrass control than single applications 8 weeks after first application. Corn yield was not affected by herbicide application timing and was 70% less in untreated plots than in treated plots. The results of this study in addition to published results in previous studies suggest that an application of either nicosulfuron or primisulfuron 4 to 6 weeks after planting can allow a grower an option of determining if a second application is necessary. Growers not able to inspect treated fields or reluctant to make two applications for johnsongrass control should make a single application at a labeled rate 6 to 8 weeks after planting.

INTRODUCTION

Johnsongrass was declared by Holm *et al.* (6) as the sixth most serious weed in the world. Hafliger and Scholz (5) reported that johnsongrass was widely distributed in America (North, Central, and South), Africa, Europe, Asia, Australia, New Zealand, Philippines, Indonesia, and the Pacific islands. Johnsongrass infestations in corn reduce both grain quality and quantity and, if severe enough, prevent grain production (1).

Bendixen (2) reported that fall plowing and herbicide applications provided effective (greater than 90%) johnsongrass control in corn in a 3 year rotation with winter wheat and soybean. Fall plowing and herbicide applications provided less than 50% control in monocultured corn. Recently, the sulfonylurea herbicides nicosulfuron and primisulfuron were registered for post-emergence control of rhizome johnsongrass (plants emerged from perennating tissues) in corn. Camacho *et al.* (4) reported that although these herbicides display soil activity, neither herbicide prevented regrowth from johnsongrass rhizomes within treated soils. Field studies (4, 7) revealed more consistent control of rhizome johnsongrass with split applications of nicosulfuron and primisulfuron at a 0.5X rate (17.5 and 20 g ai/ha, respectively) 2 weeks apart compared to single applications at a 1.0X rate at the early date. An additional study was deemed necessary to compare split applications of both herbicides at either 0.5 plus 0.5X or 0.75 plus 0.25X rates with single applications at 0.5, 0.75, and 1.0X rates.

METHODS

A corn field naturally infested with rhizome johnsongrass in north-eastern Kansas (dryland) was selected. Soil texture was a Grundy silty clay loam (22% sand, 50% silt, and 28% clay) with 2.2% organic matter and pH 5.9. Plots consisted of four corn rows spaced 0.76 m wide and 7.5 m long. Jacques 8210 hybrid was planted 23 April 1991 and the field immediately treated with alachlor and atrazine at labeled rates to control annual weeds (including seedling johnsongrass) and permethrin at a labeled rate to control cutworms, *Agrotis spp.*

Treatments consisted of nicosulfuron and primisulfuron applied as single applications at 0.5, 0.75, and 1.0X rates (1.0X = 35 and 40 g/ha, respectively) on 28 May or as split applications at 0.5 plus 0.5X or 0.75 plus 0.25X rates with the second application made on 11 June. All treatments contained a nonionic surfactant (X-77, Valent USA Corp.) at a concentration of 0.25% (v/v). Herbicides were applied with a CO_2-pressurized plot sprayer equipped with flat-fan nozzles calibrated to deliver 187 L/ha at 276 kPa. Untreated plots served as checks.

Corn injury and johnsongrass control were visually rated at 4 and 8 weeks after treatment (WAT), respectively, on a scale of 0 to 100, where 0 indicated neither stand nor growth reduction and 100 indicated plant death. Corn yields were determined by hand harvesting ears from 4.5 m of each of the two middle rows of each plot, shelling the corn, and correcting kernel weights for moisture content.

Treatments were assigned in a split-plot arrangement with herbicides as main plots and application timings as subplots. A randomized complete block design with four replications was used. Analysis of corn injury and johnsongrass control ratings did not include those for check plots to avoid the use of zeros and therefore creating unequal variances. Treatment means were separated by Fisher's protected l.s.d. test at P=0.05.

RESULTS AND DISCUSSION

Interactions between herbicides and application timing were not significant for corn injury, rhizome johnsongrass control, or corn yield. Therefore, only herbicide and application timing main effects are presented (Table 1).

Both nicosulfuron and primisulfuron injured corn slightly which was evident at 4 but not 8 WAT. Injury was lowest with single applications. Nicosulfuron provided greater rhizome johnsongrass control averaged across application timing than primisulfuron. Greater control of rhizome johnsongrass with nicosulfuron compared to primisulfuron was also observed in earlier studies in north-eastern Kansas under dryland conditions (4). Camacho *et al.* (3) reported greater foliar absorption of radiolabeled nicosulfuron compared to primisulfuron in rhizome johnsongrass cultured in the greenhouse which explains the greater activity of nicosulfuron.

Rhizome johnsongrass control with split applications averaged across herbicides was excellent (greater than 95%). Control with split applications (combined rate = 1.0X) was significantly greater than with single applications made at the earlier date at 0.5 or 0.75X rates and tended to be greater than a single application at the 1.0X rate. We attribute most of the increase in efficacy of split applications to the effect that the second application has on plants previously treated but not completely killed (and producing new shoots) and some of the increase in efficacy to control of plants that emerged after the earlier application date. Without the second application, most of the late emerging plants would survive the first application because soil activity with both nicosulfuron and primisulfuron is minimal (4).

Corn yield was not significantly affected by herbicide averaged across application timing. Also, no significant differences in corn yield occurred between herbicide applications applied as single or split applications. Corn yield in untreated plots was 70% less than the average yield for the treated plots. This indicates that rhizome johnsongrass is a very competitive weed.

A grower applying nicosulfuron or primisulfuron at 0.5 to 0.75X rates at an early date (4 to 6 weeks after corn planting) may choose not to make the second application 2 weeks later (or substitute row cultivation for the herbicide application) if treated plants are satisfactorily controlled and few if any late-emerging plants are present. The grower however must determine if treated plants are recovering and if plants are emerging since the herbicide was applied. A grower who is reluctant to perform a second operation (herbicide application or row cultivation) should consider a single application at the full labeled rate when essentially all rhizome johnsongrass plants have emerged and most plants have more than five leaves present (7). A previous study (4) revealed that single applications at a 1.0X rate 6 to 8 weeks after planting provided equivalent johnsongrass control as split applications in corn grown under dryland conditions in north-eastern Kansas.

Table 1. Effect of nicosulfuron and primisulfuron and application timing on rhizome johnsongrass control and corn injury and yield in north-eastern Kansas in 1991

Herbicide	Application timing[b]	Corn injury[c] (%)	Johnsongrass injury[c] (%)	Corn yield (kg/ha)
			Herbicide main effect[a]	
Nicosulfuron	--	11	1.33 (97)	4720
Primisulfuron	--	16	1.21 (92)	4050
l.s.d. = 0.05		NS	0.11	NS
			Application timing main effect	
--	½ x early	8	1.13 (88)	4930
--	¾ x early	10	1.23 (93)	5290
--	1 x early	13	1.25 (95)	4930
--	½ x + ½ x	20	1.35 (97)	4670
--	¾ x + ¼ x	18	1.39 (98)	5000
--	None	--	--	1510
l.s.d. = 0.05		6	0.15	710

[a] Herbicide by application timing interaction was not significant at P=0.05 for all parameters.

[b] Full rates (1x) for nicosulfuron and primisulfuron were 35 and 40 g/ha, respectively.

[c] Visual ratings for corn injury and johnsongrass control were taken at 4 and 8 weeks, respectively, after the first application was made. Johnsongrass control ratings were arcsine-transformed for statistical analysis; values in parentheses are nontransformed values.

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TERBUTRYNE PLUS MCPA FOR SEEDLING SAFFRON THISTLE *(CARTHAMUS LANATUS)* CONTROL IN WINTER CEREALS

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Summary. A proprietary mixture of terbutryne (275 g/L) plus MCPA (160 g/L as potassium salt) was evaluated for the control of seedling saffron thistle *(Carthamus lanatus)* when applied 6 weeks after sowing wheat and barley. During 1991 and 1992 one replicated logarithmic dose trial and two replicated fixed dose trials were conducted in farmer established crops. At 1.5 L/ha of the proprietary mixture, saffron thistle at the 2-7 true leaf stage was well controlled. The 1.0 L/ha rate of the proprietary mixture required the addition of 12 g/ha clopyralid for similar control of saffron thistle. Both treatments resulted in a significant grain yield increase.

INTRODUCTION

Saffron thistle *(Carthamus lanatus)* is an erect annual which germinates from autumn to early spring. Saffron thistle competes with cereal seedlings for moisture and nutrients early in the growing crop. If not controlled, dense stands may present problems at harvest and the seeds can contaminate grain. The Australian Wheat Board and Australian Barley Board both have receival standards for saffron thistle seed contamination. Wheat or barley exceeding these standards is downgraded.

Herbicides registered for use in wheat and barley for early post-emergent control of saffron thistle include diuron and bromoxynil/MCPA mixtures. Phenoxy herbicides are registered for saffron thistle control once cereals commence tillering and are effective for the control of later germinations of saffron thistle.

In 1986, research conducted in South Australia found that a tank mixture of terbutryne (425 g/ha) + MCPA amine (150 g/ha) applied to saffron thistle seedlings at the 10cm rosette stage provided 67% control in wheat (2). In the same trial, clopyralid (150 g/ha) alone or mixed with MCPA amine (150 g/ha) resulted in 93% & 98% control respectively (2).

In 1987, MCPA amine (250 g/ha) plus clopyralid (15 g/ha) applied as a tank mixture provided 99% control of saffron thistle in a medic based pasture. The medic tolerance to this treatment was unacceptable (1).

METHODS

<u>Logarithmic Dose Trial</u>. The trial site in Spear wheat had a uniform distribution of saffron thistle (3 - 5 true leaves), stemless thistle (*Onopordum acualon)* (2-4 true leaves), medic and a range of other broad-leaved weeds. Herbicides were applied using a Chesterford Mini-Log Sprayer. The trial design was a randomised complete block with 3 replicates. The proprietary mixture was applied as either a peak dose with reducing rates or as the proprietary mixture at a fixed rate and clopyralid at a peak dose with reducing rates. The distance required to halve the dosage was 7 meters. Plots (1x28 m) were assessed for the herbicide dose required for complete control of each weed species as determined from the half dosage distance.

Fixed Dose Trials. The trial design was a randomised complete block with 5 treatments and 4 replications of plots (3x10 m). Herbicides were applied 6 weeks after sowing in 100 L/ha at 220 kPa pressure using a hand held spray boom.

The trial site in Yagan barley had a low pre-spray density (11 plants/m ^{2}) of saffron thistle seedlings (4-7 true leaves) and a range of other broad-leaved weeds. Weed counts were recorded at 65 days after spraying (Table 2). Due to poor crop growth, no grain yields were obtained from this trial.

The trial site in Schooner barley had a high pre-spray density (39 plants/m^2) of saffron thistle seedlings (cotyledon - 7 true leaves) and a range of other broad-leaved weeds. Weed counts were recorded at 176 days after spraying (Table 2) . Grain yield was obtained by harvesting the entire plot.

RESULTS AND DISCUSSION

The logarithmic dose trial indicated that complete seedling saffron and stemless thistle control could be obtained with 1.5 L/ha of the proprietary mixture (412 g/ha terbutryne + 240 g/ha MCPA K salt) (Tmt 1., Table 1). When the 1.0 L/ha rate of the proprietary mixture was fixed (Tmt 2. Table 1) the addition of 9 g/ha clopyralid provided complete control of saffron thistle and stemless thistle. Medics tolerated 1.5 L/ha of the proprietary mixture alone, but were very sensitive to low rates of clopyralid.

Table 1. Herbicide rates (grams a.i./ha) required for complete control of saffron thistle, stemless thistle and Medicago spp. in Spear wheat.

Herbicide Treatment	Saffron thistle (g/ha)	Stemless thistle (g/ha)	Medics (g/ha)
1. Terbutryne + MCPA (K salt) (Rate reducing from 1100+640 g/ha)	412 +240	412 + 240	688 + 400
2. Terbutryne + MCPA (K salt) (Rate fixed at 275+160 g/ha)	275 + 160	275 + 160	275 + 160
+ Clopyralid (Rate reducing from 30 g/ha)	+6	+9	+3

In the two fixed dose trials (Table 2), 1.5 L/ha (Tmt 4) of the proprietary mixture (412 g/ha terbutryne + 240 g/ha MCPA K salt) provided 94% and 85% control of saffron thistle respectively. Under heavy weed pressure in Schooner barley, the 1.0 L/ha rate (Tmt 2) resulted in unacceptable control (68%). In this case the addition of 12 g/ha of clopyralid (Tmt 3) markedly improved saffron thistle control. The tank mixture (Tmt 5) recommended but not registered for saffron thistle control in South Australia provided (95%) control in Schooner barley.

Significant grain yield increases were recorded in all herbicide treatments. Although a range of other broad-leaved weeds were also controlled, grain yield increases can be mainly attributed to saffron thistle control. Saffron thistle plants that did survive herbicide treatment were suppressed with no visible flower heads at harvest. Grain from untreated plots contained a high level of saffron thistle seed contamination.

Table 2. The effect of herbicide treatments on saffron thistle density and grain yield in barley

Treatment	Yagan Barley Saffron Density (% Control) [plants/m²]	Schooner Barley Saffron Density (% Control) [plants/m²]	Schooner Barley Grain Yield (% of Untreated) [tonne/ha]
1. Untreated	0 [11]	0 [39]	100 [0.64]
2. Terbutryne + MCPA (K salt) (275 g/ha) + (160 g/ha)	82	68	140
3. Terbutryne + MCPA (K salt) (275 g/ha) + (160 g/ha) plus + clopyralid (12 g/ha)	88	95	133
4. Terbutryne + MCPA (K salt) (412 g/ha) + (240 g/ha).	94	85	139
5. MCPA (amine) + clopyralid (500 g/ha) + (15 g/ha)	73	95	141

These results indicate that 1.5 L/ha of this proprietary mixture is effective for saffron thistle control in wheat and barley. At the 1.0 L/ha rate, the addition of a low rate of clopyralid is needed for effective saffron thistle control in cereals.

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EFFECTIVE WEED CONTROL TECHNOLOGY FOR DRY SEEDED RICE IN KOREA

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Summary. Newly developed direct seeding method, high-ridged dry seeding of rice, was evaluated on yield performance with stability, weed ecology, and effective weed control method. This new direct seeding method resulted in as much grain yield and stability as the conventional mechanical transplanting method through good seed germinability and uniform seedling growth. Several herbicide recommendations were summarized. Basically, two (or three) herbicide applications were needed, one (or two) at the period of upland soil condition and another one at the period of permanent flooding condition.

INTRODUCTION

Recent international and local socio-economic situation made a significant change in agricultural research activity in Korea: better grain quality in varietal improvement program and low production cost in cultivation technology development program to meet international market competition. Currently, more than 90% of rice area is transplanted by mechanical transplanter (58% for aged seedling, 30-35 days old and 33% for infant seedling, 8-10 days old) while remaining areas are mostly manually transplanted (12). Labor hour requirement of rice crop was 540 hrs/ha for Korea (5), 480 hrs/ha for Japan (5), and 25 hrs/ha for USA (14).

Since 1987 the Yeongnam Crop Experiment Station has intensively studied on developing new technology of direct seeding method in rice crop and thus released a new technology, high-ridged dry seeding method. The success of this technology was almost relied on the successful control of weeds. The paper discusses mainly effective weed control measures.

METHODS

Tractor attachable rice drill seeder can be manipulated either high ridged seeding or flat seeding. One way passing of this seeder produce 6 seeding rows making about 50 cm canal in the center and the digged soils in this canal are used as seed covering material to both sides. Land was not plowed until seeding date to minimize the harmful effect of excessive rainfall. Only one or two rotavations is needed for seeding. Basal fertilizer was manually broadcasted just before rotavation. One hundred sixty kg/ha of nitrogen was applied in 5 splits with the rate of 30% for basally, 20% for 3 leaf stage, 20% for 7 leaf stage, 20% for panicle initiation stage, and 10% for flowering stage, respectively while phosphorus (90 kg/ha) and potassium (110 kg/ha) were all applied as basally. After one or two rotavations, well cleaned intact seeds were sown at the rate of 50 kg/ha and followed by one canal irrigation which is essential in this technology. For the first 30-40 days until rice leaf reaches 4-5 leaves the field maintained upland condition and thereafter maintained flooded condition as normal paddy rice field.

Herbicide research and weed ecology were mostly concentrated on the first 30-40 days (upland soil condition period). The herbicides used during the experimental period were mostly marketable herbicides for transplanted rice in Korea. Herbicides were basically tested in three stages: *stage 1*, for pre-emergence both in rice and weed; *stage 2*, for pre- and post-emergence (pre-emergence of rice and post-emergence of weed); and *stage 3*, for post-emergence both in rice and weed. Crop protection and other cultural practices were followed by the standard methodology for rice crop in Yeongnam Crop Experiment Station (15) while those for data collection was followed by Rural Development Administration (13).

RESULTS AND DISCUSSION

Advantages of High Ridged Seeding Technology

Since 1987 the author published several research papers related on high ridged dry seeding: for seeding method (2, 3, 11), for seeding time (8, 10), for seeding rate (4), for water management (6), for weed control (7, 9), for yield potential and stability (2), and for economic analysis (3), respectively. A series of this research resulted in several advantages of this technology. One canal irrigation just after seeding provided quite a stable environment for seed germination and thus resulted in better seed germination, seedling growth, lodging tolerance, herbicidal efficacy and minimized the harmful effect of barley straw, stubble and other crop residues in double cropping, excess soil moisture damage, and herbicidal phytotoxicity.

The productivity of this technology for 6 years was 4.52 t/ha in polished rice which was 98% of transplanted rice while coefficient of variation of this yield was 8.5% for new technology and 6.4% for transplanted rice, respectively (Table 1).

Table 1. Comparison of the yield productivity between mechanical transplanting and high-ridged dry drill seeding (polished rice, t/ha)

Year	Mechanical transplanting (A)	High-ridged dry drill seeding (B)	Index (B/A)
1987-1992	4.60	4.52	98
CV%	6.4	8.5	-

Effective Weed Control Method

Weed ecology. Among the rice cultivation methods dry seeding method resulted in the greatest weed growth and thus weed control is of prime importance in success of the new technology. During experimental period (1987-92) yield loss due to weed growth was 70-100% for dry seeding, 40-60% for water seeding, 30-35% for mechanical transplanting of infant seedling (8-10 days old), 25-30% for mechanical transplanting of aged seedling (30-35 days old), and 10-20% for manual transplanting, respectively. More than two fold of weed was harvested at dry seeding than at manual transplanting.

Shift of cultivation method from transplanting to dry seeding resulted in change of not only total weed biomass but also floristic composition. Recently the occurrence of *E. crus-galli* has rapidly increased.

This was not an important weed in 1980 weed survey. Recently, herbicides were predominantly developed as a mixtures with sulfonyl ureas which have relatively poor efficacy to grasses. And also, labor shortage and high labor wage resulted in a tendency to reduce tillage operation and poor water management. These all might be contributed to increase of *Echinochloa* species. One other possible contribution is the possibility of the development of herbicide resistant strain.

After three years consecutive dry seeding of rice the floristic composition was drastically changed. The most important weed species was *Echinochloa* species having dominance of 47.2% followed by *Digitaria adscendens* (9.6%), *Aeschynomene indica* (7.5%), *Leptochloa chinensis* (6.7%), etc. One interesting thing was the occurrence of weedy rice.
The occurrence of weedy rice might possibly be originated from shattered grain in previous year, outcross among cultivated cultivars, and/or outcross between cultivated rice cultivar and red rice. Strictly speaking, the term of weedy rice imply the collective term of a descendant between cultivated rice and wild rice (1). Author, however, included the above three categories as weedy rice.

Chemical control. Even though there is an increasing awareness of the importance of the integrated weed management concept herbicide is working on key factor on this concept particularly in dry seeding method.It can be said that herbicide recommendations are well established in irrigated rice field and thus it was focused mainly on first 30-40 days of upland period.

Table 2. Herbicidal efficacy of several soil applied herbicides as affected by irrigation regime

Herbicide (a.i. g/ha)	Water solubility (ppm)	Flushing*		Canal irrigation	
		Phytotoxicity (1-9)	Herbicidal efficiacy (%)	Phytotoxicity (1-9)	Herbicidal efficacy (%)
. butachlor (1800)	240	1.2	83	1	60
. thiobencarb (2800)	30	1.0	85	1	45
. chlomethoxyfen/ butachlor (2700)	0.3/240	1.0	86	1	60
. pyrazolate/ butachlor (2850)	0.05/240	1.0	85	1	55
. pyrazoxyfen/ butachlor (2850)	0.9/240	1.0	86	1	60
. butachlor/ bensulfuron-methyl (801)	240/8	2.0	95	1	65
. mefenacet/ bensulfuron-methyl (789)	8/8	1.5	94	1	50
. thiobencarb/ bensulfuron-methyl (1539)	30/8	1.5	94	1	60
. molinate/ pyrazosulfuron-ethyl (1521)	800/221	1.5	96	1	85
. thiobencarb/ pyrazosulfuron-ethyl (1521)	30/221	1.5	95	1	76

* Flushing: 3-6 hours flooding.

Several granular herbicides currently use in transplanted rice were screened the herbicidal performance and phytotoxicity as pre-emergence application. Most of herbicides performed better at flushing of water (3-6 hours flooding just after herbicide application) than canal irrigation (Table 2). Among herbicides the mixture of molinate/pyrazosulfuron-ethyl had the greatest herbicidal efficacy in both water regimes. Effective herbicide recommendations for new direct seeding technology were summarized in Table 3 based on 5 years research.

Among those, just before the rice emergence about 12-15 DAS application of herbicide mixtures of pre-emergence soil-treatment herbicides and post-emergence foliar application herbicide were particularly effective throughout the experimental period.These were propanil mixtures : propanil+butachlor, propanil+pendimethalin, and propanil+thiobencarb. The maximum safety and good herbicidal efficacy can be achieved by application of these herbicides at just before rice emergence but weeds are almost complete their emergence. *Echinochloa* species were usually emerged faster than rice by 4-6 days. As mentioned early one additional herbicide application was needed just after permanent irrigation about 40 days after seeding. Therefore, basically two (sometimes three) herbicide applications are needed for this new technology, one (or two) application for dry period and another one for flooding period. Non-selective contact herbicides of paraquat, glyphosate, or glufosinate ammonium are sometimes applied either single application before seeding or tank mix application with butachlor, pendimethalin or thiobencarb for controlling the developed weeds such as *Alopecurus aequalis*.

Table 3. Effective herbicides for controlling weeds in dry seeded rice

Application time	Herbicide (formulation)	Dosage (kg a.i./ha)	Phytotoxicity (1-9)	Efficacy (%)	Test year
0-5 DAS* (phase 1)	. pendimethalin (32.7EC)	1.60	1	75-93	1990-93
	. pyrazosulfuron-ethyl/ butachlor (0.07/2.5G)	0.77	1	70-92	1991-93
	. pyrazosulfuron-ethyl/ thiobencarb (0.07/5G)	1.52	1	73-95	1991-93
	. pyrazosulfuron-ethyl/ molinate (0.07/5G)	1.52	1	70-92	1991-93
	. mefenacet/bensulfuron-methyl/dymron (3.5/0.13/1.5G)	1.54	1	73-93	1991-93
	. pyrazosulfuron-ethyl/ quinclorac (0.07/1G)	0.32	1	90-95	1991-93
	. bensulfuron-methyl/ quinclorac (0.17/1G)	0.35	1	88-92	1991-93
12-15 DAS (phase 2)	. propanil + butachlor (35 + 33 EC)	1.4+1.3	1	92-98	1989-93
	. propanil + pendimethalin (35 + 31.7 EC)	1.4+1.3	1	95-98	1990-93
30-35 DAS (phase 3)	. quinclorac/bentazon (10/40 WP)	1.5	1	90-98	1989-93

* DAS; days after seeding.

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CYHALOFOP BUTYL: GRASS HERBICIDE - FIELD PERFORMANCE IN RICE IN JAPAN -

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Summary. Cyhalofop butyl, (R)-butyl 2-(4-(4-cyano-2-fluorophenoxy)phenoxy) propionate is a new grass herbicide having outstanding selectivity between rice and *Echinochloa crus-galli*, even under conditions in which rice seedling roots are directly exposed to paddy water. The safety margin for japonica rice was over 10 times greater than the rate required for control of *E. crus-galli*. Cyhalofop butyl had consistent performance under a variety of paddy management conditions, combining rapid knockdown with short soil residuality. Neither selectivity nor efficacy was affected by leaching conditions. In field trials in Japan, cyhalofop butyl controlled *E. crus-galli* up to 4 leaf stage as a granule application and up to 6.5 leaf stage as a foliar spray, without injury to rice.

INTRODUCTION

Cyhalofop butyl, coded XDE-537 (DEH-112 in Japan), is a new post-emergence aryloxyphenoxy propionate herbicide discovered by DowElanco. Cyhalofop butyl has high selectivity between rice and target grass weeds, due to different metabolism of the molecule (1). Cyhalofop butyl kills target grass weeds within one week after application. The purpose of the present work is to elucidate the herbicidal properties of cyhalofop butyl for rice in granule and foliar spray applications.

METHODS

Field trials. In 1989 and 1990 seasons, field trials were carried out at Fukuoka field station of DowElanco division in Japan. After the paddy field was rotary-tilled, puddled and levelled, target weed seeds were infested. Rice seedlings at 2.5 leaf stage were transplanted into the paddy field at a planting depth of approximately 2 to 3 cm by transplanter a few days after levelling. The plots were separated by corrugated plastic boards. Trials with a plot size of 6 m2 were block randomised with 3 replications. The granular formulation of 0.6% cyhalofop butyl was broadcasted by hand onto the water surface at appropriate timings. The EC formulation of 30% cyhalofop butyl was sprayed over the top of plants by a knapsack sprayer at 1000 L/ha of spray volume with a wetting agent at 0.03%. The water in the test plots was maintained at 3 to 4 cm deep during trial period. Weed control efficacy and crop injury were visually evaluated in comparison with the untreated plots 2 and 4 weeks after application. The soil characteristics were alluvial soil, 55.9% sand, 26.7% silt, 17.5% clay, 3.4% organic matter, CEC 20.8 meq/100 g and pH 6.5. One cm of water loss in depth was observed in a day.

Pot trials. Soil was puddled and leveled in the 1/5,000 are Wagner's pot. Pot trials for residual activity, leaching and crop tolerance were conducted at Gotemba laboratory of DowElanco in 1989 and 1990. A water level trial was conducted at Fukuoka field station in 1992 under greenhouse conditions. For the residual trial, 30 pre-germinated seeds of *E. crus-galli* were settled on the soil surface in the pot at designed days after application (0, 3, 7, 14 DAA) and

Abbreviations: EC, emulsifiable concentrate; Gr, granule; LF, leaf stage; DAA, days after application; a.i., active ingredient.

evaluated 2 weeks after seeding by visual rating with 3 replications. Water level was maintained at 3 cm. For the leaching study, *E. crus-galli* at 2 leaf stage was treated with cyhalofop butyl granules and maintained under leaching conditions at 5 cm/day for 2 days from 1 day after application with 3 replications. For the tolerance study, one group of 2.5 leaf stage rice plants were transplanted at a planting depth of 3 cm and the other were settled on the soil surface with their roots exposed to the paddy water directly. They were treated 1 day after transplanting with 3 replications. The characteristics of Gotemba soil were humic volcanic ash soil, 29.5% sand, 44.6% silt, 25.9% clay, 5.95% organic matter, CEC 67.5 meq/100 g and pH 6.25. For water level trial, *E. crus-galli* at 3 leaf stage was applied with granules of cyhalofop butyl at the water depth of 1, 2 and 3 cm with 3 replications and the water depth was maintained for 4 weeks. Temperature of both greenhouses was kept at 30°C in the daytime and 20°C in the night.

RESULTS AND DISCUSSION

<u>Weeding spectrum (field trial).</u> Cyhalofop butyl at 180 g ai/ha gave perfect control of 1 to 3 leaf stage of *E. crus-galli*, while it did not control any annual and perennial broad leaves and sedges (Table 1).

Table 1. Weed control spectrum of cyhalofop butyl at 180 g ai/ha (field trial)
% weed control 4WAA

	Time of application		
	1	2	3 LF
Echnichloa crus-galli	100	100	100
Cyperus difformis	0	0	0
Monochoria vaginalis	0	0	0
Annual broad-leaved weeds	0	0	0
Scirpus juncoides	0	0	0
Cyperus serotinus	0	0	0
Sagittaria pygmaea	0	0	0

<u>Activity of cyhalofop butyl on *E. crus-galli* (field trial).</u> The granular formulation of 0.6% cyhalofop butyl gave perfect control of 3 and 4 leaf stage *E. crus-galli* at 180 and 360 g ai/ha, while the EC formulation in foliar spray exhibited perfect control of 5 and 6.5 leaf stage *E. crus-galli* at 240 and 600 g ai/ha, respectively (Table 2).

<u>Residual activity (pot trial).</u> Residual activity of cyhalofop butyl was observed up to 3 days after application at 180 g ai/ha (Table 3).

<u>Effect of leaching on activity of cyhalofop butyl (pot trial).</u> There was no significant difference in the activity of cyhalofop butyl on *E. crus-galli* under leaching and non-leaching conditions (Table 4).

<u>Effect of water level on the activity of cyhalofop butyl (pot trial).</u> Deep water conditions gave better control of *E. crus-galli* than shallow water (Fig. 1). Cyhalofop butyl required a minimum water depth of 3 cm to maximise performance.

Tolerance (pot trial). Granular cyhalofop butyl at 1,080 and 2,190 g ai/ha (6 and 12 times recommended use rate) caused no injury to 2.5 leaf stage rice seedlings transplanted at a planting depth of 3 cm, and very slight/slight injury to rice seedlings of with roots directly exposed to paddy water (Table 5). No phytotoxicity was observed on rice below 1,080 g ai/ha under the exposed conditions. The symptom of injury was slight browning of leaf tips without reduction of height and weight. Cyhalofop butyl had outstanding rice selectivity, even under conditions in which rice seedling roots were directly exposed to paddy water. The safety margin of the granular formulation for japonica rice was over 10 times greater than the rate (180 g ai/ha) required for control of 3 leaf stage *E. crus-galli*. Foliar spray treatment (field trial) was also highly selective to japonica rice (Table 6).

Table 2. Activity of cyhalofop butyl on *E. crus-galli* (field trial)

% *E. crus-galli* control 4WAA

Treatment application	Rate g ai/ha	Time of application				
		2	3	4	5	6.5 LF
Cyhalofop butyl	600	100	100	-	100	100
30% EC	300	100	100	-	100	-
Foliar spray	240	-	100	-	100	86
	180	100	100	-	80	-
Cyhalofop butyl	360	100	100	100	83	-
0.6% Gr	180	100	100	85	63	-
	90	97	93	70	47	-
	45	80	73	-	-	-
Quinclorac	600	100	100	98	80	-
1% Gr	300	100	100	87	70	-
	150	98	73	60	27	-
	75	67	40	23	-	-

Table 3. Residual activity of cyhalofop butyl in granule (pot trial)

% control of *E. crus-galli* seedlings

Cyhalofop butyl 0.6% Gr	Interval between herbicidal application and seeding			
	0	3	7	14 days
180 g ai/ha	100	98	45	16

Efficacy was evaluated 2 weeks after seeding

Table 4. Effect of leaching on activity of cyhalofop butyl (pot trial)

Treatment	Rate g ai/ha	% *E. crus-galli* control 4WAA	
		Leaching	Non-leaching
Cyhalofop butyl 0.6% Gr	180	98	99
	90	90	88
Quinclorrac 1% Gr	300	85	97
Mefenacet 4% Gr	1,200	60	60

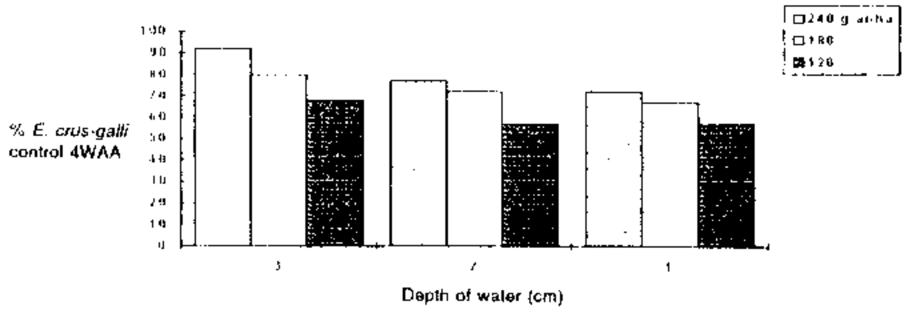

Figure 1. Effect of water depth on activity of cyhalofop butyl

Table 5. Tolerance of rice plants granular against cyhalofop butyl in under different transplanting conditions (pot trial) 2WAA

Treatment	g ai/ha	Planting depth			
		3 cm		0 cm	
		Visible injury	Plant height % of untreated	Visible injury	Plant height % of untreated
Cyhalofop butyl	2,160	Nil	97	Slight	99
0.6% Gr	1,080	Nil	99	Very slight	102
	720	Nil	103	Nil	104
	360	Nil	99	Nil	111
Mefenacet 4% Gr	1,200	Nil	101	Significant	54
Untreated	-	-	100	-	100

Rice at 2.5 leaf stage was treated 5 days after transplanting

Table 6. Tolerance of rice plants against cyhalofop butyl in foliar spray (field trial)

Injury 2WAA

Treatment	g ai/ha	Growth stage		
		3	4	5 LF
Cyhalofop butyl	450	Nil	Nil	Nil
30% EC	300	Nil	Nil	Nil

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AC 322,140 - A NEW HERBICIDE FOR USE IN TRANSPLANTED PADDY RICE IN JAPAN

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Summary. AC 322,140 is a new broad-spectrum herbicide being developed for weed control in transplanted rice in Japan as well as other rice growing countries. In field trials in Japan, AC 322,140 showed good selectivity to rice cultivars and provided excellent persistent control of major annual weed species including *Cyperus difformis, Monochoria vaginalis, Elatine triandra, Lindernia procumbens*, and perennial weeds such as *Eleocharis acicularis, Scirpus juncoides, Sagittaria pygmaea, S. trifolia* and *Cyperus serotinus* with both pre-emergence and post-emergence applications at rates of 45 to 60 g a.i./ha. The persistent and consistent performance demonstrated in field testing is also well supported by several findings in greenhouse studies illustrating the unique properties of AC 322,140.

INTRODUCTION

AC 322,140 (1-{[O-(cyclopropylcarbonyl)phenyl]sulfamoyl}-3-(4,6-dimethoxy-2-pyrimidinyl)-urea) is a new selective herbicide belonging to the sulfamoylurea class of herbicides. This broad-spectrum herbicide was discovered and is being developed by American Cyanamid Company. It has unique chemistry and mode of action, and is active against a wide variety of broad-leaved weeds and sedges with good selectivity to rice plants (1). AC 322,140 is now under development for weed control in transplanted paddy rice in Japan as well as other rice growing countries. The present paper describes the biological performance of AC 322,140 through field trials conducted in Japan, and some in Korea, Taiwan, Indonesia and Thailand since 1990. Also, several findings in greenhouse studies at Tahara Agricultural Center relating to it's performance are presented.

METHODS

Field Trials. AC 322,140 0.15% extruded clay granule (G) and 0.2% G formulations were field tested in transplanted paddy rice from 1990 to 1992. All treatments were replicated three times with a plot size of 2x3 m. Treatments were made by hand post-transplanted to rice at Pre-emergence to Post-emergence from 0 to 15 DATR (days after transplanting). Appropriate commercially available products were used as references. Plots were visually assessed at various times during the growing season.

Greenhouse Test. Greenhouse testings were carried out at Tahara Agricultural Center usually using loam soil in pots to clarify the biological properties of AC 322,140 as a rice herbicide.

RESULTS AND DISCUSSION

Field Trials. In Japan, field trials have been conducted under different climatic conditions during three seasons. The results presented here summarize 6 trials carried out in the cool area of Hokkaido, in the moderately warm area of Aichi on Honshu and in the warm area of Kagoshima on Kyushu in 1991 (Table 1).

AC 322,140 at the rates of 45 to 60 g/ha provided excellent control of annual and perennial broad-leaved weeds and sedges tested such as *Monochoria vaginalis*, *Lindernia procumbens*, *Sagittaria pygmaea*, *S. trifolia*, *Scirpus juncoides* and *Cyperus serotinus*. AC 322,140 partially suppressed annual grass, *Echinochloa crus-galli*, however, control was not sufficient. Crop tolerance of AC 322,140 at the rate of 45 to 60 g/ha was excellent in these trials.

Table 1. Average weed control of AC 322,140 treated at Pre-emergence, Early post-emergence and Post-emergence in paddy rice fields, 1991/Japan

Treatment	Rate (g a.i./ha)	Application Timing	% Control at 2 MAT								Phyto-toxicity %
			ECHCR	CYPDI	MOOVA	LIDPY	SAGPY	SAGTR	CYPSE	SCPJU	
AC 322,140	45	2 to 5 DATR	64	95	99	89	92	97	94	99	0
	60		68	95	99	91	93	93	95	99	0
Bensulfuron /mefenacet/dymron	51/1,050/450	"	97	97	91	91	94	97	94	97	0
Pyrazosulfuron /mefenacet	21/1,050	"	95	97	76	86	94	100	94	98	2.5
AC 322,140	45	5 to 10 DATR	70	97	99	99	98	100	95	95	0.2
	60		76	98	98	99	99	99	94	97	0.6
Bensulfuron /mefenacet/dymron	51/1,050	"	97	98	92	93	97	100	98	92	0.5
Pyrazosulfuron /mefenacet	21/1,050	"	93	97	77	84	91	100	96	93	0.5
AC 322,140	45	7 to 15 DATR	64	98	99	98	99	95	95	99	0.8
	60		74	99	100	99	99	93	95	99	0
Bensulfuron /mefenacet/dymron	51/1,050/450	"	98	98	99	95	99	90	95	95	0
Pyrazosulfuron /mefenacet	21/1,050	"	97	98	99	89	97	100	92	96	0.5

ECHCR: *Echinochloa crus-galli* CYPDI: *Cyperus difformis* MOOVA: *Monochoria vaginalis*
LIDPY: *Lindernia procumbens* SAGPY: *Sagittaria pygmaea* SAGTR: *Sagittaria triforia*
CYPSE: *Cyperus serotinus* SCPJU: *Scirpus juncoides*

Under poor growing condition, however, some growth retardation was observed, but this symptom is transient and further growth is not affected.

At different application timings, AC 322,140 showed consistently effective weed control at pre-emergence stage of weeds (2 to 5 DATR), early post-emergence (5 to 10 DATR, 1 leaf stage of rice) and post-emergence (7 to 15 DATR, 2 leaves stage of rice).

In these trials the assessments were done at about 2 months (56 to 67 days) after treatment and at these later timings, standard products like bensulfuron-methyl/mefenacet/dymron and pyrazosulfuron-ethyl/mefenacet showed some regermination of annual weeds and *S. juncoides* by earlier application while AC 322,140 gave almost perfect efficacy at any application timing. These results suggest the excellent persistent weed control of AC 322,140 is superior to these standard products.

AC 322,140 also showed excellent to good herbicidal activity against *Rotala indica*, *Lindernia angustifolia*, *Ludwigia prostrata*, *Elatine triandra* and *Eleocharis kuroguwai* in Japan. Similar promising results have been found in other Asian countries such as Taiwan (tested at 20-50 g a.i./ha), Korea (20-60 g a.i./ha), Indonesia (20-60 g a.i./ha) and Thailand (wet-sown rice, 20-60 g a.i./ha).

Greenhouse studies. Results of a leaching study using soil columns being leached with 3 cm of water at 1 day after treatment indicate low mobility of AC 322,140 in soil (Figure 1).

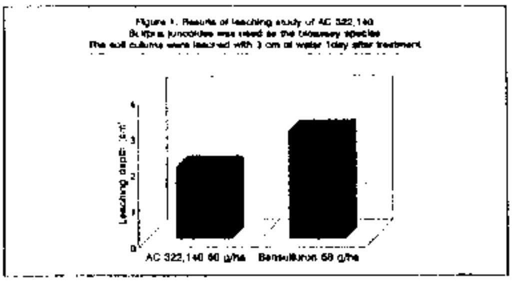


Figure 1. Results of leaching study of AC 322,140
Scirpus juncoides was used as the bioassay species
The soil columns were leached with 3 cm of water 1day after treatment

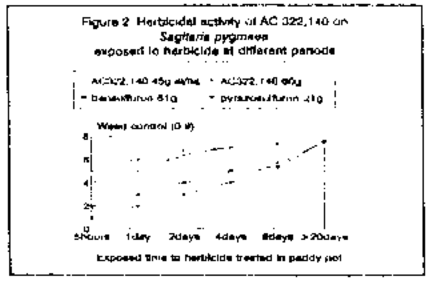


Figure 2 Herbicidal activity of AC 322,140 on *Sagittaria pygmaea* exposed to herbicide at different periods

In a test designed to measure speed of uptake, just germinated *S. pigmaea* tubers were exposed to herbicide treatment on a paddy soil for different lengths of time. The results demonstrate a faster uptake of AC 322,140 by weeds than bensulfuron or pyrazosulfuron (Figure 2).

AC 322,140 also provided excellent activity against *S. pygmaea* and almost completely inhibited the reproduction of tubers for 7 months after treatment. In contrast, besulfuron and pyrazosulfuron treated *S. pygmaea* produced high numbers of tubers (Table 2).

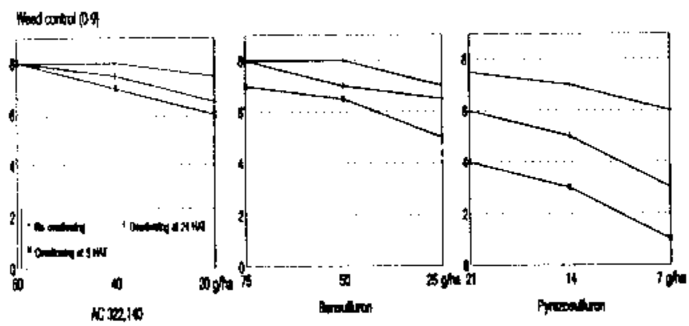
Table 2. Herbicidal activity of AC 322,140 on Sagittaria pigmaea /Effect on the reproduction of tubers

Treatment	Rate (g/ha)	Averaged numbers of tubers at 7 months after treatment
AC 322,140	40	0
	60	0
Bensulfuron	68	31
Pyrazosulfuron	28	13
Untreated	-	56

Treatment: October 25, 1991. Assessment: May 25, 1992
4 tubers/plot were planted on October 28 1991 Replication:2

To examine the influence of overflow of paddy water after treatment on weed control, a simulated overflow test was carried out according to the method developed by H. Morita (2). Results suggested that AC 322,140 performs better under overflow condition than bensulfuron or pyrazosulfuron (Figure 3).

Figure 3. Influence of overflow on the herbicidal activity of AC 322,140
Scirpus juncoides



In pot tests using 8 kinds of Japanese paddy soils, AC 322,140 showed consistent selectivity to rice and efficacy in *S. juncoides* (Table 3).

Table 3. Crop selectivity and herbicidal activity of AC 322,140 (60 g/ha) in 8 different paddy soils in Japan

Soil	Selectivity (% of control)		Weed control (0 - 9)* *Scirpus juncoides*
	Plant height	Dry weight	
Naganuma:Alluvium/Clay loam	101	96	8
Furukawa:Alluvium/Clay loam	104	100	8
Tochigi:Volcanic/Loam	99	99	8
Shiga:Alluvium/Loam	103	94	8
Kagawa:Alluvium/Sandy loam	104	95	8
Kagoshima:Alluvium/Sandy loam	99	95	8
Toyokawa:Deluvium/Loam	98	97	8
Tahara:Alluvium/Loam	96	95	8

Selectivity Variety: KOSHIHIKARI Application: 2 DATR
Leaching: 3 cm/day x 2 days
Assessment: 25 DAT

Weed control - Application: Pre-emergence
Leaching: No leaching
Assessment: 30 DAT

* Visual assessment score: 0 (no effect) 9 (completely killed)

These results from both field and greenhouse tests indicate AC 322,140 is a promising new rice herbicide with improved consistency and persistent weed control on a wide range of annual and perennial broad-leaved weeds and sedges. AC 322,140 has the potential to be combined with *E. crus-galli* herbicides and further research and development in that regard is underway in many rice-cultivating countries.

ACKNOWLEDGEMENTS

The authors wish to thank Cyanamid field teams in the regions, especially Messrs Y. Ikeda and Y. Handa, who carried out the trial works presented in this paper, and also Dr M. Trimmer for his assistance in the preparation of this paper.

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ENVIRONMENTAL WEEDS IN TASMANIA

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Summary. A series of workshops in the south, north and north-west of Tasmania identified and prioritised plants considered to be environmental weeds in different land use systems - Bushland reserves, Native forestry, Roadsides, Riparian systems and Agricultural land. The major weeds identified were gorse (*Ulex europeaus*), blackberries (*Rubus fruticosus* agg.), brooms (*Genista monspessulana* and *Sarathamnus scoparius*), pampas grasses (*Cortaderia* spp), ragwort (*Senecio jacobea*) and boneseed (*Chrysanthemoides monilfera*).

INTRODUCTION

Environmental weeds have been defined as "those species that invade native communities or ecosystems, being undesirable from an ecological perspective, but not necessarily an economic one" (1). For this paper the above definition has been slightly altered to cover any community or ecosystem not those that are just native. This is because plants that are considered weeds in one landuse system generally are weeds in other landuse systems. If effective control of weeds in any landuse system is to be achieved, recognition of the status of the concerned plant in neighbouring systems needs to be taken into account and any conflicts need to be resolved prior to implementation of any control strategy. Aims of the workshops were to identify the major environmental weeds in Tasmania across all landuse systems in order to get a co-ordinated community approach into any weed strategy being implemented.

METHODS

Three identical workshops were held in the south, north and north-west of Tasmania during August 1992. The aims of the workshops were to identify major weed problems in different landuse systems and prioritise weed control in these systems. The workshop was divided into three sections:

- plenary session
- identifying environmental weeds of different land use systems (group workshop)
- formulating control strategies for specific weeds (group workshop).

The land use systems that participants worked on were Bushland reserves, Native forestry, Roadsides, Riparian systems and Agricultural land.

Participants classified the area of infestation according to the size of infestation and distribution (Table 1). A control priority rating was also given to the majority of weeds listed. The priority rating used was the same as (1), shown in Table 1.

In the final session, participants worked on control strategies for individual weeds, collating information to form a control strategy - the combination of the three workshops covered 13 weeds being blackberry (*Rubus fruticosus* agg.), boneseed (*Chrysanthemoides monilifera*), brooms (*Genista monspessulana* and *Sarothamnus scoparius*), crack willows (*Salix fragilis*), fennel (*Foeniculum vulgare*), glyceria (*Glyceria maxima*), gorse (*Ulex europeaus*), paspalum

(*Paspalum dilatatum*), pampas grass (*Cortaderia* spp.), sweet pittosporum (*Pittosporum undulatum*), thistles (*Carduus*, *Cirsium* and *Silybum* spp), ragwort (*Senecio jacobea*) and spanish heath (*Erica lusitanica*).

Table 1. Ratings of Weed distribution and urgency for initiating control measures

Weed Distribution Rating	Urgency for initiating control measures*
1. Widespread (medium to large population)	1. Critical (as soon as possible)
2. Widespread (small population)	2. Very High (within two years)
3. Limited distribution (medium to large population)	3. High (2-5 years)
4. Limited distribution (small population)	4. Medium (6-10 years)
5. Localised (medium to large population)	5. Management measures in place
6. Localised (small population)	

* from (1)

RESULTS AND DISCUSSION

Although both ratings were used, only the ratings on urgency for action is reported. The distribution rating is necessary to determine the amount of resources that will be required to enact effective control methods.

Bushland reserves. This area had the most weeds rated as category 1. Many of these weeds were listed at only one of the workshops, reflecting the need for control of specific plants on a regional basis. Weeds listed as category 1 were blackberry, boneseed, broom, cape ivy (*Senecio millanoides*), cotoneaster (*Cotoneaster* Spp.), gorse, hawthorn (*Crataegus monogyna*), marrum grass (*Ammophila arenaria*), pampas grasses, sweet pittosporum, ragwort, rice grass (*Spartina anglica*), spanish heath and *Urosperma dalechampi*.

Native Forestry. Only two weeds, pampas grasses and ragwort were considered to be in category 1. Other weeds such as gorse, broom, blackberry, and thistles were given rating between 2-4, recognising the impact these weeds have but acknowledging control measuresin practice.

Riparian systems. Weeds listed as requiring urgent action (category 1) were fennel, parrots feather (*Mryiophyllum aquaticum*), ragwort, rice grass, and thistles. Rice grass and ragwort were listed in at least two workshops. Both crack willow and gorse were put in category 2 as it was felt that replacement species were required, prior to or as these species are controlled in order to maintain river bank stability.

Roadsides. Weeds rated in category 1 were broom, cape wattle (*Albizzia lophantha*), cotoneaster, fennel, gorse, glyceria, pampas grasses, paterson's curse (*Echium plantagineum*), ragwort and various thistles. Weeds in this system were generally given a high priority due to the roads being corridors into fragile areas.

Agricultural. As with native forestry only a few species were rated as category 1 being *Amaranthus* spp, glyceria, African feather grass (*Pennisetum macrourum*), ragwort, serrated tussock (*Nassella trichoma*) and nodding thistle (*Carduus nutans*). Only ragwort was rated in all workshops.

The weeds that are causing problems across most landuse systems throughout Tasmania were gorse, blackberries, broom, pampas grasses, ragwort, and boneseed. Although of these only boneseed is listed as one of Australia's top environmental weeds (1), the problems these weeds cause is being recognised by various community groups. Environmental weeds are the focus of Landcare groups throughout Tasmania, with the majority of groups targeting the major weeds, gorse, blackberries, broom, pampas grasses, ragwort, and boneseed. However, other groups are focusing on specific weed problems such as rice grass and willows that affect their local area. On the west coast of Tasmania, a group is formulating a control strategy involving all users of the area. This area forms a boundary to and dissects the Tasmanian Wilderness World Heritage Area. It is estimated that 30% of Tasmania's flora species are now naturalised plants of which half are invasive species (1).

As weeds tend to ignore human implemented boundaries, weed control programmes need to be managed accordingly. Instead of using land ownership to enforce weed control, control strategies should be planned using the whole water catchment of a district as the starting point. These strategies will require the co-operation and resources of whole communities. When whole communities become involved with weed control not only will present weed problems become less daunting, new weed infestations will be more quickly recognised and bought under control.

ACKNOWLEDGMENTS

Participants and presenters of the workshops are gratefully acknowledged for their willingnEs3, input and continued concern over the spread of weeds in Tasmania. A detailed report of the workshop is available from the author.

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THE CURRENT STATUS OF WEEDS IN SELECTED NATIONAL PARKS OF SOUTH EAST QUEENSLAND

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Summary. A survey has shown that weed infestations in some national parks in south-east Queensland are extensive and probably uncontrollable. Lar'e areas require restoration. The worst invasions are historical due to practi#es which were totally incompatible with biological conservation. Some species are invading natural areas with little if any human assistance. The problem can only get worse as the remaining unprotected natural areas are fragmented and destroyed by development.

INTRODUCTION

Some of the greatest problems for conservation biology are resource over-use, pollution, and exotic invasions (3). Resource use and pollution can be managed but exotic invasions are often permanent and in many cases uncontrollable. Over the recent past, Australia has concentrated on enlarging the estate for nature conservation purposes with minimum attention being given to management. Weeds form an acute and insufficiently appreciated ecological problem with formidable management and control implications (4). These statements are reinforced by a survey of six National Parks situated on the Sunshine Coast between 50 and 100 km north of Brisbane. The area is sub-tropical with an annu!l rainfall of 1500 to 2000mm. Parks supporting three different broadly defined ecosystems, mountain heathland, heathland and forest were surveyed. The mountain heathland areas contain unique and rare heaths on their slopes, with relict species that were once more widely distributed. The heathland parks are characterised by large poorly drained areas which support heath or *Melaleuca quinquenervia* forests and woodlands. The forest parks are situated on the edge of a basalt plateau with rugged terrain. The ridges and escarpments support open forest with closed forest on the better soils in the gorges. All parks surveyed have, or are being rapidly isolated from surrounding natural vegetation by development. Extensive areas have been disturbed, particularly by logging and grazing.

METHODS

It was necessary to select a survey sampling method which was fast, reasonably accurate, objective as possible and non-destructive. A grid system with transects across ecological boundaries was considered most appropriate but this needed modification because of terrain, especially cliff lines and impenetrable vegetation, usually weeds. All drainage lines were followed if practicable as these represented naturally disturbed areas. 180 km of transect were completed for the survey, many travelled in both directions. Measurements recorded were modified during the survey. Initially a density was calculated for each weed encountered but a subjective cover measurement became relevant for areas where weeds dominated the landscape. Weed infestations were followed off transect to establish their range. With the use of aerial photographs it was possible to extrapolate point data with reasonable confidence to produce weed density distribution maps.

RESULTS AND DISCUSSION

An overview of the survey is shown in Table 1. The percentage of each park estimated as free of weeds does not necessarily reflect the magnitude or importance of the problem. Seventy species of weed were recorded. This total would be greater if all species in highly disturbed areas had been identified.

Table 1. Overall result of weed survey for six national parks in south-east Queensland

National Park	Area (ha)	% weed free	Weed status	Greatest problem species
Mt Coolum	72	80	Reasonable	*Cinnamomum camphora*
Mt Tibrogargan	692	40	Quite good	*Pinus elliottii*
Mooloolah	670	95	Reasonable	*Baccharis halimifolia*
Pumicestone	2000	40	Bad	*B. halimifolia/P. elliottii*
Kondalilla	327	10	Very bad	*Lantana camara/Desmodium intortum*
Mapelton Falls	26	20	Fairly bad	*L. camara/Ageratina riparia*

Herbs and grasses accounted for 50% of the total but most were found in highly disturbed areas with no apparent ability to invade natural systems. The growth form of weeds causing serious problems or potentially serious invaders identified are shown in Fig. 1.

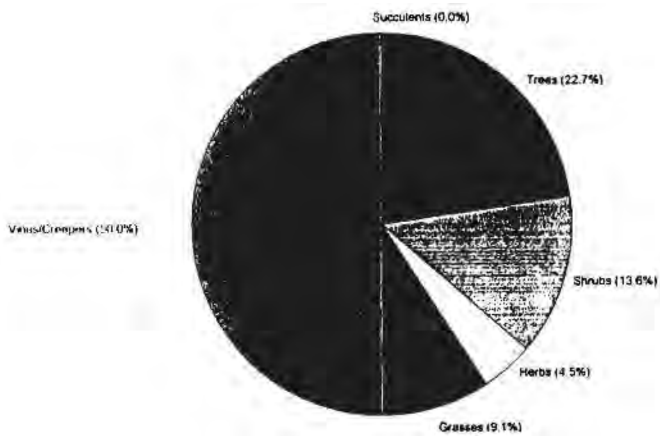

Figure 1. Growth form distribution of 22 problem weeds in selected national parks of south-east Queensland.

The most invasive environmental weeds encountered are shown in Table 2.

Lantana, *Lantana camara*. Lantana is present in 14% of the survey area. The percentage is much greater for the two rainforest parks. Lantana is an efficient pioneer species making use of both natural and anthropogenic disturbance. It grows best on the richer soils, but sparse stunted patches occur on very poor shallow soils. Large areas of Kondalilla and Mapelton Falls National Parks have a 100% understorey of impenetrable Lantana. These areas have been cleared or are logged tall open forest. It also occurs in open forest in patches, with dense stands occurring where the canopy has been opened by logging, tree fall or landslides. In the other parks it usually grows on drainage lines on the better soils. Because of its cost to agriculture in many countries of the world, conservatively estimated at five million dollars per annum in Queensland alone (1), biological control has received a lot of attention with 23 insects released. Three species have slowed the rate of spread but the great difficulty in Australia arises from the wide diversity of weedy *Lantana camara* taxa and their varying susceptibility to attack from natural enemies.

The only hope of control in natural areas is an integrated approach, changing the physical and biological environments, using biological control, manual small area clearing and active regeneration. Lantana is preventing soil erosion on steep slopes, so rapid removal is not advisable. Lantana is widely distributed throughout the whole region, and as it is readily dispersed by birds, complete eradication is an impossibility.

Table 2. List of problem weeds of different ecosystems in order of perceived threat

Closed forest and tall open forest	Coastal systems	Open forest and woodland	Heath
Lantana camara	*Pinus elliottii*	*Lantana camara*	*Pinus elliottii*
Desmodium intortum	*Baccharis halimifolia*	*Pinus elliottii*	*Baccharis halimifolia*
Tradescantia albiflora	*Lantana camara*	*Baccharis halimifolia*	*Melinis minutiflora*
Anredera cordifolia	*Cinnamomum camphora*	*Cinnamomum camphora*	
Rubus ellipticus		*Schefflera actinophylla*	
Ligustrum sinense		*Caesalpinia decapetala*	
Macfadyena unguis-cati		*Ageratina riparia*	
Ageratina riparia		*Melinis minutiflora*	
Zebrina pendula		*Passiflora suberosa*	
Ligustrum lucidum		*P. subpeltata*	
Caesalpinia decapetala		*Desmodium uncinatum*	
Cinnamomum camphora			
Passiflora subpeltata			

Groundsel, *Baccharis halimifolia*. This is a very widespread weed in the region. It is present in 30% of the survey area. Groundsel can grow in areas with low nutrient levels although seedlings are very sensitive to phosphorous deficiency. It can grow in soils with pH ranging from 3.8 to 8.2 (5). Groundsel's biological characteristics include (6):

- prolific seed production - up to one million seeds per plant in the open - it is a member of the Asteraceae family noted for seed production;
- long range dispersal;
- ability to produce viable seed under low light;
- wide tolerance to pH;
- tolerance to low nitrogen;
- survives flooding and drought; and
- ability to sprout new shoots after fire.

In Mooloolah and Pumicestone National Parks it has filled a structural niche not occupied by native species. It is the only understorey species in some *Melaleuca quinquenervia* and *Allocasuarina* spp. forests. Dense stands of groundsel grow along the transitional zone between salt marsh and open forest. The species is salt tolerant and the sea spray probably provides the essential phosphorous for the species spectacular success in this area. In the other parks, Groundsel is usually restricted to highly disturbed areas and drainage lines, its presence enhanced by the plumes of nutrients from developed areas. As infestations are so extensive with many patches inaccessible, biological control is the only viable long term control solution.

Slash Pine, *Pinus elliottii*. This weed is invading about 17% of the total area surveyed but potentially has a much greater range. It appears capable of invading, without anthropogenic disturbance, all ecosystems in the area except montane heath, closed forest and areas with permanent water. Slash pine has no significant disease or insect pests, which gives it a competitive advantage over most native species. Pumicestone National Park is being invaded along most of the eastern boundary, a length of 20 km. The species has progressed on average a distance of 160 m into the park. As the species produces seed in about ten years, the wind dispersed invasion wave should progress on average 15 m per annum. The rate of spread will be enhanced by the species radiating from a number of isolated nuclei established by bird dispersal. A detailed count was taken along six randomly selected transects each 10 m wide and the results averaged (Fig. 2). Other studies (2) have found that the number of exotic pines invading a native forest fell more or less logarithmically with increasing distance from a plantation - a pattern which reflects the distribution of a wind dispersed seed and supported by this study. The maximum density found was 58 trees per square metre. There is an estimated half a million trees in the park.

Mt Tibrogargan National Park is also extensively invaded by slash pine. The weed has been successfully removed from 50% of the park which indicates it is a species which can be controlled by manual effort. It is easy to identify and easy to destroy. There is a conflict of interest in this region as slash pine is a major plantation timber resource.

Other weeds. Species presenting significant management problems include camphor laurel, *Cinnamomum camphora*, *Desmodium intortum* and wandering jew, *Tradescantia albiflora*. Camphor laurels are readily dispersed by fruit eating birds. These trees could pose an insufficiently appreciated potential problem. There are numerous seed sources, the trees were found in most open-forest situations and they are difficult to identify and kill. *Desmodium intortum* is a vine which is rapidly increasing its range at Kondalilla. Small remnant rainforest parks are particularly vulnerable to vines. Wandering jew can reproduce asexually completely covering an area, to the total exclusion of all native species. The species loves water but is very drought resistant. It is very well established on flood plains at Kondalilla.

Conclusions. Humans have significantly influenced the distribution of weeds in National Parks. Timber exploitation, with little regard to the environment, is responsible for the worst infestations. Some areas which were partially cleared for agriculture are now 100% weeds. Some weeds including slash pine are expanding their range without human disturbances. Development is ensuring that the parks will become biologically isolated islands. The whole situation is exacerbated by park boundaries bearing no relationship to the ecology of the area.

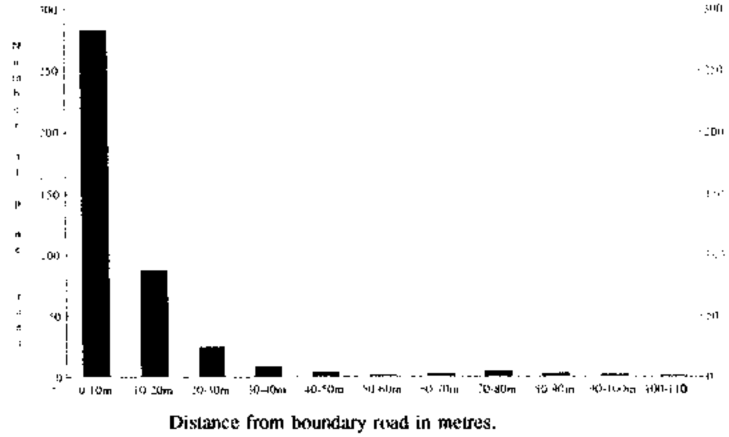

Figure 2. Pumicestone National Park - Average distribution of slash pine in six 10 m wide transects with increasing distance from the boundary road.

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WEEDS OF WESTERN AUSTRALIA'S WEST COAST OFFSHORE ISLANDS

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Summary. The West Coast region of Western Australia, stretching from Perth to Shark Bay contains some 200 offshore limestone islands. These islands have relatively simple ecosystems with high levels of natural and human disturbance. Surveys have identified 101 species of naturalised plants on these islands. Of these 9 are of very minor importance, another 62 of minor importance but needing monitoring, and 30 of major significance. The minor weeds are listed, and the major weeds are briefly disscussed in an annotated list. The most serious weeds are ***Lavatera arborea, Lycium ferrocissimum*** and ***Zantdeschia aethiopica*** which alter plant communities. The annual grasses (*Avena, Bromus* and *Ehrharta* species) are currently implicated in the decline of the Lancelin Island Skink.

INTRODUCTION

Over 2,000 islands are spread unevenly along Western Australia's long coastline, over three major biogeographic regions (Tropical Coast, West Coast and Southern Coast). Many of these islands are of crucial importance to the conservation of endangered mammals, which are now extinct on the mainland. They are also important breeding sites for birds and seals (2). These islands have relatively simple ecosystems with high levels of natural disturbance, often with superimposed human disturbance. Approximately 224 species of naturalised plants have been recorded from these islands.

Within the study area, the West Coast region stretching from Perth to Shark Bay, are approximately 200 vegetated islands. These islands are all composed of limestone or sand over limestone and are generally close to the coast. The most distant being the Abrolhos Group, some 40 km offshore.

There is a considerable body of published information (1), plant collections and unpublished observations on the flora of these islands, especially those close to Perth. (These references are contained in a bibliography prepared by N. Gibson and M. Lyons to be published by Department of Conservation and Land Management (CALM) later this year.) However, these studies are of limited value in determining management for nature conservation as they are concentrated on the few accessible islands, the naturalised flora was poorly documented (for example, there were no records of Boxthorn on any of the Lancelin-Dongara islands), and there are considerable gaps in the documentation of the native flora of the islands, particularly in relation to the annual flora.

Recent floristic surveys of many of these islands have been made by the author and other CALM staff to collect specific records of weeds and vegetation changes to assist in the preparation of management plans (3,4).

METHODS

The island surveys were by extensive foot traverse in Autumn and Spring to ensure collection of herbaceous weeds. Some control measures were undertaken using advice on appropriate herbicides from the Agricultural Protection Board. Monitoring is currently in progress.

RESULTS AND DISSCUSSION

The weeds recorded in the survey are grouped according to management priorities which relate to their impact on nature conservation values. Three groups are distinguished. Group 1 is very minor weeds with no obvious impact therefore of low management priority, i.e. no management or monitoring. Group 2 is minor weeds defined by no obvious impact but potential impact possible therefore of low management priority, i.e. no management but monitoring is required. Group 3 is the major weeds that require management as indicated below.and associated monitoring.

Very minor weeds. These weeds have only been recorded on islands with permanent settlements, Rottnest and Garden Islands. They are *Allium ampeloprasum, Allium sativum, Narcissus tazetta, Ornithogalium umbellatum, Arundo donax, Typha orientalis, Cotula bipinnata, Riccinus communis* and *Ficus carica*. With the exception of *Cotula bipinnata*, a kerbside weed on Rottnest Island, they are all garden escapes. Recent surveys (1992) have shown that previously recorded minor garden escapes have died out (3,5). The 9 listed species are those still persisting in 1992. It is considered unlikely that any will become even minor weeds.

Minor weeds. The following 62 species are minor weeds, either confined to very disturbed areas, or having no apparent deleterious effect on the nature conservation values of the islands on which they occur. They are listed alphabetically under families, then genera

Monocotyledons

Poaceae: *Aira caryophyllea, Aira cupiana, Briza maxima, Catapodium rigidum, Ehrharta villosa, Lagurus ovatus, Lolium multiflorum,.Lolium rigidum, Paralophis incurva, Phalaris minor, Poa annua, Trisetaria cristata* and *Vulpia myorus*.

Dicotyledons

Aizoaceae: *Tetragonia decumbens.*
Asteraceae: *Arctotheca calendula, Arctotheca populiifolia, Conyza albida, Conyza bonariensis, Conyza parva, Dittrichia graveolens, Hedypnois rhagadioloides, Hypochaeris glabra, Lactuca serriola, Pseudognaphalium luteo-album, Vellereophyton dealbatum.*
Brassicaceae: *Brassica tournefortii, Cakile maritima, Hymenobolus procumbens, Sisymbrium erysimoides, Sisymbrium irio.*
Caryophyllaceae: *Cerastium glomeratum, Corrigiola littoralis, Polycarpon tetraphyllum, Sagina maritima, Spergularia diandra, Spergularia rubra,*
Crassulaceae: *Crassula glomerata.*
Euphorbiaceae: *Euphorbia paralias, Euphorbia peplus, Riccinus communis*
Fabaceae: *Lotus angustissimus, Medicago polymorpha, Melilotus indica, Trifolium campestre, Trifolium dubium, Trifolium glomeratum.*
Geraniaceae: *Erodium cicutarium, Pelargonium capitatum .*
Gentianaceae: *Centarium erythraea, Centaurium spicatum .*
Malvaceae: *Lavatera cretica, Malva parviflora .*
Orobanchaceae: *Orobanche minor.*
Oxalidaceae: *Oxalis pes-caprae.*
Phytolaccaceae: *Phytolacca octandra.*
Polygonaceae: *Emex australis.*

Portulacaceae: *Portulaca oleracea*.
Primulaceae: *Anagallis arvensis*.
Rubiaceae: *Galium murale*, *Sherardia arvensis*.
Scrophulariaceae: *Dischisma arenaria* and
Solanaceae: *Solanum nigrum*.

Major weeds

Monocotyledons

Agavaceae: *Agave americana*/*Agave sisalana*. Recorded only as a garden escapes on Rottnest Island. Removed physically in 1990 because of tourist injury fears
Anthericaceae: *Trachyandra divaricata*. Common on beaches on many islands. Considered a serious weed of mainland coastal dunes (6). Monitored but control measures would be extremely difficult. On Garden Island widespread but in low density, apparently controlled by tammar grazing.
Araceae: *Zantdeschia aethiopica*. Serious invasive weed of *Acacia* shrublands on Garden Island where it was replacing the native understory. Being eradicated over a five year program of grided herbicide spraying funded by the Navy. Monitoring and spot spraying to continue after the major program ends. A management program to rehabilitate seriously affected areas is being prepared. Scattered clumps are known from Rottnest Island, and are being eliminated.
Asphodelaceae: *Asphodelus fistulosus*. Recorded from 16 islands. Potentially serious on Rottnest, where it has replaced heath after severe disturbance. Cessation of disturbance, animal exclosures and replanting is needed in these areas. Apparently not grazed by quokkas.
Asparagaceae: *Myrsiphyllum asparagoides*. Garden escape on Garden Island, and apparently controlled by grazing tammars. Being closely monitored. On adjacent mainland is a very serious weed of the same vegetation associations.
Iridaceae: *Ferraria crispa*/*Homeria flaccida*. Garden escape on Rottnest Island and invading heathland. Potentially very serious weeds, as both are highly unpalatable to quokkas and hence are at an advantage compared to many palatable native seedlings after fire or other disturbance. A monitoring and control program is needed.
Poaceae: *Avena barbata*, *Avena fatua*, *Bromus diandrus*, *Bromus hordeaceus*, *Bromus madritensis* and *Ehrharta longiflora*. All are common weeds of open areas and bird rookeries on most islands. As they colonise otherwise unvegetated land they were not initially considered as serious weeds. However recent work on Lancelin Island suggests they may have contributed to the decline of the critically endangered endemic Lancelin Island skink by filling the open areas used as feeding and basking sites by this lizard. A management program to control these species is being prepared.
Cynodon dactylon and *Stenotraphum secundatum*. Garden escapes on Rottnest Island. Invading *Melaleuca lanceolata* woodlands edging salt lakes, smothering native herbs and shrubs. Controlled by herbicides.

Dicotyledons

Aizoaceae: *Mesembryanthemum crystallinum*. Largely confined to bird rookeries on many islands and are believed to change soil chemistry to favour this species at the expense of other native herbs. Widespread and not being controlled at present.
Asteraceae: *Carduus pycnocephalus*, *Centaurea melitensis* and *Cirsium vulgare*. Common weeds of disturbed areas of the islands off Perth. These appear to be largely an amenity

problem (i.e. people don't like walking through them). Numbers decline markedly after disturbance ceases.

Sonchus oleraceus, *Sonchus tenerrimus* and *Urospermum picroides*. Common on the drier islands north of Perth. Again these are common disturbance weeds which require monitoring and small scale management in public areas. There ecological effects are poorly known.

Chenopodiaceae: *Chenopodium album* and *Chenopodium murale*. Very common species on old seabird rookeries. Being monitored in case these species replace grasses when these are removed from Lancelin Island.

Malvaceae: *Lavatera arborea*. This species has invaded four islands in the Perth area and is replacing the native *Lavatera pleibea* var *tomentosa*. The species is being physically removed from Shag Island as part of the management plan for the Shoalwater Islands.

Myrtaceae: *Agonis flexuosa*. This aggressive native species has been introduced to Garden Island, where it is already seeding prolifically. A known weed outside its natural range, seedlings of the planted trees, which have historical significance, will be removed and the trees not replaced.

Solanaceae: *Lycium ferocissimum*. Numerous infestations have been recorded on offshore islands. The most severe infestations being on Lipfert, Orton and the East Beagle islands. Apparently reaches the islands when birds eat the succulent fruits on the adjacent mainland. This summer deciduous species replaces the evergreen native shrub *Nitraria billardierei*, which is used as nursery shelter by seals and their pups. Evidence from Victoria (7) suggests this species is also deleterious to nesting seabirds. Plants are sawn off close to the base using long handed saws, and the stumps painted with herbicide in diesel. Tops are either removed to a beach or the mainland and burnt (when in fruit) or used to provide seed traps to help revegetate the area where they were removed.

Nicotiana glauca. This species has invaded *Callitris preissii* woodland on the mainland at Woodmans Point opposite Garden Island. Plants of this species are present in low numbers on the island and have been removed to prevent a similar invasion occuring.

Urticaceae: *Urtica urens*. There is a massive infestation of this species on Tern Island. There are no data on possible causes or effects of this species. Requires monitoring as it is present in much smaller populations on many islands.

One hundred and one species of weeds have been recorded from these islands. Approximately one third of these are considered to require management intervention to lessen their deleterious effects.

The most serious weeds appear to be either shrubs (for example *Lavatera arborea* and *Lycium ferocissimum*) or perennial herbs (for example *Homeria flaccida*, *Myrsiphyllum asparagoides* and *Zantdeschia aethiopica*) which can alter the structure and function of island plant communities.

Control of the major weeds requires a degree of co-ordination as most are distributed across numerous islands and CALM management areas. Each species requires a management program that applies throughout its range. Currently management programs are operating on the large settled islands off Perth. These are slowly working towards integrated programs to deal with current and potential weed problems.

Most of the minor weeds are annual species and are considered of little importance in priority for management. However the implication of gap filling annual grasses (and perhaps the replacement of these when controlled, by the broad-leafed annuals, Chenopods and Thistles) in the decline of the Lancelin Island skink suggest that we need to keep an open mind in assessing the threat posed by all naturalised flora. Consequently, the monitoring of minor weeds so that we can respond to the unexpected effects of these species is vital.

Currently CALM Science and Information Division has established databases on the mammals and seabirds of Western Australia's offshore islands. As the plant surveys continue a similar database is being established for the native and naturalised flora. These combined datasets should enable integrated planning to preserve the diverse natural values of our offshore islands from the threat of weeds. The aim should be for pro-active management once we have overcome the current crop of established weeds.

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NATURALISED WEEDS OF RAINFORESTS AND ASSOCIATED HABITATS IN TROPICAL QUEENSLAND

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Summary. The four exotic plant species harungana (*Harungana madagascariensis*), turbina (*Turbina corymbosa*), sanchezia (*Sanchezia parvibracteata*) and coffee (*Coffea arabica*) occur as weeds of rainforests and associated habitats in subcoastal tropical north Queensland. The biology, ecology, distribution, impact and control of each is summarised.

HARUNGANA

Harungana (*Harungana madagascariensis* (Choisy) Poir.) is an evergreen small tree from Madagascar and East Africa (5).

Harungana trees branch repeatedly under well lit conditions to produce a domed crown about 5 m high. Several growth cycles occur each year, each producing about eight pairs of oval strongly veined leaves. The shoots and undersides of leaves are covered with minute rusty brown hairs, which together with the dark green upper surfaces of the leaves and the domed crown give the plant a characteristic appearance.

The 2-3 mm diameter white flowers are minutely flecked with black, and are borne in dense corymbs at the tips of the shoots. They are pollinated by insects which visit for nectar, and develop into globular 2-3 mm diameter yellow fruits containing five minute and tightly adherent pyrenes, which are distributed as a single unit by frugivorous birds. Harungana also spreads locally by vigorous suckers from damaged and intact roots, giving rise to dense clumps of trees and suckers in more open areas.

In Madagascar and throughout tropical Africa harungana is a plant of rainforest margins and abandoned land (2, 3). Its habitats in north Queensland closely follow this pattern, although it is also present in dense rainforest following severe disturbance some thirty years ago.

Although present in the Babinda area of North Queensland since at least 1937 (7), harungana has only spread some 10 km north, east and south from that point in more than 35 years. Further spread by ingestion and defecation by birds is still occurring.

Harungana appears to have had little impact on the now highly disturbed and mostly cultivated vegetation of the area, but since the remaining local rainforests have recently been declared a World Heritage Area there is considerable concern as to its possible future impact.

Harungana should not be attacked physically (even by mowing lawns around existing plants) since this leads to intense suckering from the surface roots. It is susceptible to multiple stem injections of triclopyr plus picloram, glyphosate, and metsulfuron methyl based herbicides (6).

Since harungana appears to have no local value and to be readily controllable, and its widespread distribution across tropical Africa suggests that it may be in a lag phase prior to more rapid expansion in North Queensland, application has been made to have the plant declared as a P2 plant throughout Queensland. Meanwhile an attempt is being made to eradicate it by stem injection throughout the accessible areas of its known distribution in north Queensland.

TURBINA

Turbina (*Turbina corymbosa* (L.) Raf.) is a deciduous woody liane of rainforest margins from tropical America (5).

Turbina has a strong grey woody twisted stem up to 10 m long, characterised by irregular ridges and grooves. Young stems climb by spiralling round a support, but older stems often hang away from the supporting tree to form a curtain. The heart-shaped leaves are produced during the growth flush in spring, and are followed by a profusion of attractive white to cream flowers. Each flower produces a single 3-4 mm long oval woody seed, and the fruit is surrounded by persistent woody wing-like sepals.

Once established in an area (presumably by human agency), the plant appears to have no other method of seed dispersal than gravity and flood water. Plants away from watercourses tend to form small clumps or lines along the edges of rainforests, whilst those in the gallery forests along the Barron River form a more extensive and often discontinuous community that extends downstream for many kilometres.

In tropical America turbina occurs in a very wide range of habitats, although usually associated with disturbed rainforests (1). In Queensland turbina is only known to occur in dry rainforests in the Yungaburra, Atherton and Malanda area and in gallery forests along the course of the Barron River, both inland from Cairns. Its distribution appears to be static unless further occurrences are reported.

Turbina can be controlled by cutting woody stems close to the ground, perhaps assisted by the application of translocated herbicides such as glyphosate to the cut stump (6).

Although of some ornamental value, turbina is no longer sold commercially or grown in gardens. Given its restricted habitat and area in north Queensland compared to its much wider range of habitats throughout large areas of tropical South America, it has been recommended that an attempt be made to eradicate it from north Queensland.

SANCHEZIA

Sanchezia (*Sanchezia parvibracteata* Sprague and Hutchinson) is an ornamental shrub from tropical South America. It has been in cultivation there for a considerable period, and is not known from the wild (5).

Sanchezia produces many erect woody stems 2-4 m long to form, in open areas, an attractive rounded shrub. The large opposite leaves are strikingly and irregularly variegated with yellow lines, and the terminal inflorescences carry very attractive yellow tubular flowers about 5 cm long surrounded by shorter orange to red bracts. No seeds are produced in Queensland, but the plant is very easy to reproduce vegetatively.

Sanchezia is widely planted in gardens for its ornamental value, and generally fails to reproduce spontaneously when away from watercourses. When it is planted or discarded along creeks and rivers, however, it forms dense stands which actively compete with native plants. Reproduction in these cases is by fragmentation, since the brittle stems are easily broken by feral pigs and floods, and even single node cuttings float downstream and root very readily in moist soil. Individual leaves may also root but probably not shoot from the petioles.

Sanchezia has been reported to be 'usually found in gardens but sometimes growing wild along streams, possibly as an escape' in Colombia (4), a situation which is precisely mirrored by its occurrence in north Queensland. Its main occurrence as a weed is along Henrietta Creek in the Palmerston National Park, where it has been spreading downstream from material dumped or planted on the creek bank near a picnic area. Sanchezia also occurs widely throughout the Cairns area, but is usually in association with gardens or garden refuse.

Sanchezia is susceptible to foliar sprays of glyphosate (6), and it is being eliminated from National Parks in north Queensland.

COFFEE

The well known evergreen shrub coffee (*Coffea arabica* L.) from tropical East Africa and Arabia has been cultivated in North Queensland for its fruit for many years. Unlike the current areas of production, most of the earlier plantations were in areas cleared from rainforest, and as they failed the areas reverted to rainforest with coffee as a persistent weed in areas of World Heritage value (5).

The usually multi-stemmed shrubs are 2-5 m tall and carry opposite pairs of large bright green leaves. They also flower readily, and produce large numbers of fruits on better lit bushes. The seeds are spread with water along creeks and drainage lines, and are also by cassowaries. Apart from its recognisably exotic nature, coffee appears to have little impact on the functioning of rainforests in North Queensland.

As with many multi-stemmed shrubs, the best method of control appears to be by basal bark spraying with triclopyr dissolved in diesel oil (6). It is unlikely that coffee can be eradicated from the extensive areas of rainforest along the ranges behind Cairns, but it should be possible to control it in those that are in the World Heritage Area.

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ENVIRONMENTAL MONITORING OF WEED CONTROL ON ABORIGINAL LAND: A CASE STUDY

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Summary. Environmental weeds on Aboriginal lands are an emerging issue in Australia. Control of noxious weeds on these lands has, until recently, suffered sporadic and inadequate funding. In 1991, a program commenced to prevent the spread of *Mimosa pigra* on Aboriginal land in the Northern Territory. In this paper, it is demonstrated, through examples, that comprehensive research and monitoring has helped ensure that environmental goals are being met efficiently with minimal undesirable consequences. It is argued that management must be integrated with research to maintain support for similar large-scale programs to control environmental weeds on Aboriginal lands in the future.

INTRODUCTION

Environmental weeds are a major concern for nature conservation (6) and are now emerging as an issue for Aboriginal people who, in the Northern Territory (NT), control more than 40% of the land. Aborigines on these lands continue to rely in part on the natural environment to provide traditional foods. Environmental degradation through weed invasion will further disrupt traditional practices of Aborigines and increase their dependence on outside assistance. Until recently, no specific funding has been available to deal with large outbreaks of noxious weeds on Aboriginal lands (1). *Mimosa pigra* and athol pine, *Tamarix aphylla* are two species of immediate concern (6), but other environmental weeds such as rubber vine, *Cryptostegia grandiflora* may become problems in the future (6).

Weed control on Aboriginal land is distinctive because these lands are typically remote, lacking in infrastructural support, and usually are not commercially productive. Therefore the technology and assumptions of weed control programs on agricultural lands are not necessarily applicable. This paper presents a case study of a program to control an infestation on Aboriginal land of one of Australia's major environmental weeds, *Mimosa pigra*. By 1991, dense mimosa stands had covered more than 20 000 hectares of Aboriginal land in the NT (1). The easternmost large infestation of mimosa is on the floodplains of the East Alligator River at Oenpelli, where it has doubled in area every 1.4 years through the 1980s to cover about 6000 ha by 1991 (7). It has blocked access to a major area for traditional food-gathering of the Aboriginal community at Oenpelli, and has impacted on an important breeding ground for Magpie geese, *Anseranas semipalmata*. Furthermore, it threatens adjacent river systems including those of the Kakadu National Park World Heritage Area. For these reasons, the Commonwealth Government provided substantial funding to control this infestation and build upon previous smaller-scale control attempts.

The program to control mimosa at Oenpelli is the largest single program ever undertaken in Australia to prevent weed spread and restore a wetland following weed invasion. It has a high public profile and has many potentially controversial aspects. Therefore comprehensive research and monitoring is integrated into the overall control program to ensure that it is effective, efficient, and causes minimal undesirable consequences. This paper describes some of the contributions that research and monitoring has made to the control program. Funding for this work was provided by the Commonwealth Government through the Northern Territory

Department of Primary Industries and Fisheries. It is argued that integrating research and monitoring with management is crucial to maintaining public support for large-scale control of environmental weeds on Aboriginal lands.

METHODS

Study site. The main infestation of mimosa discussed in this paper occurs on the eastern floodplain of the East Alligator River (EAR), approximately 10 km north of the Aboriginal community of Gunbalanya (Oenpelli) in the Northern Territory (133°00' E 12°15' S). The EAR forms the boundary between Kakadu National Park (KNP) and Arnhemland. The floodplains are usually covered with water between late December and May/June each wet season, and dry out in the latter half of each year.

Monitoring of strategy and tactics. Initially, from 1983 until 1992, control measures focussed on the main infestation. The effectiveness of this strategy was examined by assessing the importance of satellite outbreaks to the spread of mimosa. Records of new outbreaks of mimosa in KNP were obtained from Australian National Parks and Wildlife Service (J. Madison pers. comm., 1992), and the density of new outbreaks per square kilometre of floodplain was calculated. From the relationship between density and distance from the main stand, the number of new outbreaks on previously unsurveyed wetlands in Arnhemland was predicted.

Tebuthiuron was the main herbicide used in this program. A total of 62 t of tebuthiuron were applied in November 1991 at the time recommended in the proposal, i.e. "early in the wet season, after cracks in the black soil have sealed but before flooding (in order to) minimise the movement of tebuthiuron into the soil profile" (1). The recommendation is reconsidered through studies of the mobility of tebuthiuron in the local environment (3) and literature review.

Monitoring of environmental effects. Concentrations of tebuthiuron were measured in samples of floodwater using HPLC. In November 1991 and 1992, the species composition and abundance of native flora was assessed at 200 sites representing a range of habitats and mimosa control histories across the main infestation. The species richness and herbaceous cover of sites in areas in which mimosa has never occurred were compared with that of sites treated first in 1991 and sites treated in 1988/89 and again in 1991.

RESULTS AND DISCUSSION

Prevention of mimosa spread. There was a strong negative relationship between the density of new outbreaks in KNP and distance from the main stand (Fig. 1), indicating that outbreaks of mimosa up to 60 km from Oenpelli could be attributed to seeds being spread from the main stand. It was predicted from this relationship that at least 34 new outbreaks could exist in the 610 square kilometres of floodplains within 60 km to the north of the main stand. As a result, the strategy of the control program has now changed to reflect the importance of controlling satellites. A thorough search of some of these floodplains in September 1992 found 22 outbreaks of mature mimosa plants (R. Salau pers. comm., 1992). The densities of outbreaks on the surveyed floodplains were even greater than those predicted suggesting that secondary infestations have probably occurred.

The rapid increase in the size of the main stand of mimosa at Oenpelli was, in part, the factor that convinced the Federal Government to provide funds for its control. This led, however, to the initial over-emphasis on control of the main stand. Such a misplaced emphasis on the control of the main stand is typical of most programs aimed at preventing plant invasions (9). Whereas the highest priority should be given to preventing weed spread by controlling satellite outbreaks (9). Once such strategies are in place, one can return to the less pressing problem of how to rehabilitate the land beneath the main stand.

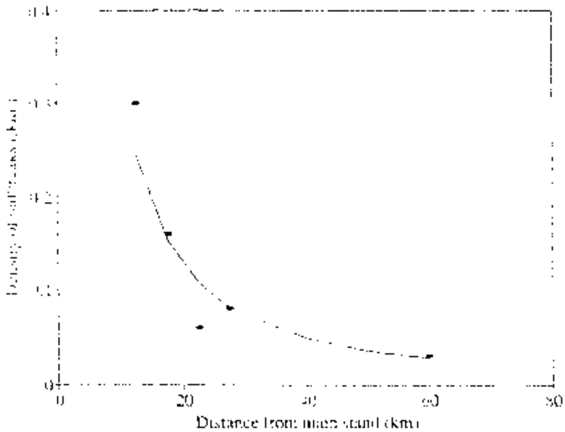

Figure 1. The relationship between the density of mimosa outbreaks in Kakadu National Park and distance from the main stand at Oenpelli; $Y = 8.4 * X^{1.4}$ $r^2 = 0.84$.

<u>Herbicide application to the main stand of mimosa</u>. Research in the USA on a sandy loam soil concluded that tebuthiuron should be applied to dry rather than wet soils to prevent runoff water from removing tebuthiuron (10). Vertisols such as those in which mimosa grows, have notoriously low infiltration rates after crack closure (11). Consequently, the practice of applying tebuthiuron after crack closure, as recommended in the NT (1), is likely to produce severe losses of the chemical through runoff. The research component of this program drew attention to this problem and independently confirmed, under local conditions (3), the results of the work in USA. The research will therefore lead to improved efficiency in the use of this herbicide, and reduce any deleterious effects of dissolved tebuthiuron in floodwaters.

<u>Environmental impacts</u>. The concentrations of tebuthiuron in two water bodies to which the herbicide was applied directly in November 1991 were 635 µg/L and 2050 µg/L several days after application. Such levels are sufficient to reduce algal production and chironomid densities (12), but are well below LC_{50} values for fish (1). By March 1991, concentrations had fallen to below 40 µg/L, and it likely that tebuthiuron would have little direct toxic effects in the aquatic systems in the long-term.

On the floodplains, the cover and species richness of native flora was lower where mimosa had invaded than where mimosa has never occurred (Table 1). On sites which were treated with tebuthiuron first in 1988/89, the native flora has partially regained its richness of species, but the cover has remained low (Table 1). Thus despite two to three years of partial control of mimosa, revegetation has not proceeded adequately. Therefore active steps are required to hasten revegetation. Although pasture species such as Koronivia grass, *Brachiaria humidicola* can provide good competition for mimosa (8), they could also outcompete native species such as *Oryza sp.* and *Eleocharis spp.* on which Magpie Geese and other waterfowl depend (5). Given the high conservation values of the Northern Territory wetlands (4), and the value placed on waterfowl as a food resource by Aboriginal people (2), sowing of introduced pastures is inappropriate and techniques will need to be developed to revegetate the wetlands with native species.

Table 1. The effect of *Mimosa pigra* and its control on the cover and species richness of herbaceous plants on the Oenpelli floodplains.

Treatment	Herbaceous cover (%)	Number of herbaceous species
Mimosa absent	47^a	4.1^a
Mimosa present, treated 1989 and 1991	36^b	3.2^b
Mimosa present, treated 1991.	31^b	1.9^c

(different letters indicate significant differences, $p<0.05$).

<u>Conclusions</u>. The success of this program to control mimosa on Aboriginal land is vital because it is costing about $A6.5 million over several years and is in an environmentally and politically sensitive area. Research and monitoring of all aspects of the ecology, toxicology, environmental chemistry, logistics, and socio-economics has contributed to several major changes in direction of this program. These changes should lead to more rapid and cost-effective control of this weed, and restoration of the wetlands for use by the Aboriginal people.

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DIFFERENTIAL RESPONSE OF FOUR PASTURE LEGUME SPECIES TO BROAD-LEAF HERBICIDES

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Summary. Results of experiments at Merredin in 1991 and 1992 on the tolerance both within and between four pasture legume species to a range of herbicides for broad-leaved weeds are presented. Leaf abnormalities were produced on some varieties with 2,4-DB and imazathepyr. Biomass reductions at anthesis were greater in the wet year, but imazathepyr and flumetsulam were tolerated best under these conditions. Seed yields were not always indicative of biomass reductions. Clear tolerance problems were experienced with terbutryne + MCPA on the barrel medics and two of the polymorpha medics, with 2,4-DB on Serena medic, and with diflufenican, imazathepyr and flumestulam on Nungarin sub-clover.

INTRODUCTION

Broad-leaved weeds such as doublegee, *Emex australis*, capeweed, *Arctotheca calendula*, and to a lesser extent corkscrew, *Erodium botrys*, continue to be weed problems in Western Australian temperate pastures. Their control has been hampered by a lack of cheap and effective herbicides which are safe to the pasture legume species grown. Broad-leaved weed control in subterranean clover, *Trifolium subterraneum*, has been extensively practiced with herbicides such as 2,4-DB (either alone or in combination with diuron) and with the spray-graze technique using 2,4-D (4). However such herbicides are either relatively expensive or capable of severely damaging the sub-clover.

In the past 10 years in Western Australia both new species and varieties of pasture legumes have been released for which little or no information has been available on their relative tolerances to herbicides. Differential responses to 2,4-DB and bromoxynil in *Trifolium* and *Medicago* species have been reported for Australia (2, 3). In both cases tolerance was assessed on herbage production, with information on seed yields provided indirectly by means of seedling regeneration in the subsequent year in one report (2). Both reports provide evidence for substantial variation both within and between legume species.

This paper presents results of experiments at Merredin in 1991 and 1992 on the differential tolerance both within and between four pasture legume species (subterranean clover vars. Dalkeith and Nungarin; barrel medic vars. Cyprus and Parabinga; polymorpha medic vars. Serena, Santiago and Circle Valley; and sphere medic var. Orion) grown in Western Australia to a range of broad-leaved herbicides.

METHODS

Sites for assessing herbicide tolerance of pasture legumes were established at Merredin on 19 June 1991 and 25 May 1992 on red brown sandy loam (pH of 6.0) over a yellowish red heavy clay at 30 cm (pH of 7.8). The 1991 growing season was generally poor with below average rainfall (146 mm) while 1992 was above average (150 mm of summer-autumn rain and 270 mm of growing season rain).

The experiments were sown with 25 kg/ha of rhizobium-inoculated sub-clover and medic seed with 100 kg/ha superphosphate (9.1% P) at seeding. A strip plot design with 4 replications was used with varieties as main plots and herbicides applied at right angles to the direction of sowing. Plots were 3x3 m. Sub-clover and polymorpha medics were tested in 1991 and all four species in 1992. Treatments were applied at the 3-5 trifoliate leaf stage of the legumes using a vehicle mounted commercial boomspray. Herbicides were applied in 70 L/ha of water using 80015LP nozzles at 150 kPa.

Biomass scores were assessed in spring at flowering of the mid-season variety Santiago using a linear score from 0 to 10 where 1 unit = 10% reduction in biomass. Seed yields were taken from two 0.0625 m^2 quadrats/plot harvested in mid December (sub-clover failed to set seed in 1991 due to the low rainfall in September/October). Seed yields were analysed using a nearest neighbour technique (Spatial Analysis of Field Experiments (1)). Seed yields from both years were quite variable resulting in high coefficients of variation. This variability in yield has been a consistent feature of seed yield results from pasture legume variety evaluation trials in Western Australia and the results reported here are not atypical for such work (D. Gillespie, pers. comm.). Consequently a 90% confidence limit has been used in calculating the seed yield l.s.d.

RESULTS AND DISCUSSION

Morphological abnormalities were produced by a number of herbicides in both seasons. 2,4-DB caused leaf cupping in most varieties but these were most pronounced in Dalkeith and Serena. In the case of Dalkeith the effects were still noticeable at flowering, with the leaves also standing more upright. Serena had darker green leaves, and the formation of flowering buds in the lower leaf axils was either non-existent or reduced. In Orion the main growing point died with subsequent initiation of new growth from the lower leaf axils.

Abnormalities produced by imazathepyr were similar to those of 2,4-DB but these were only in the polymorpha medics, with Serena being most affected. Diflufenican and the bromoxynil + diflufenican mixture gave leaf blotching and yellowing characteristic of diflufenican and this was confined to those leaves present at the time of application. Treatments with diuron, terbutryne and bromoxynil all produced leaf scorch and yellowing, and in the case of the terbutryne substantial plant death. These effects were worst on the medic species.

Biomass scores at flowering were indicative of differences between seasons, species and varieties (Table 1). The reductions in biomass were higher in 1992 than 1991 and this may be due to the wetter conditions making some herbicides more available, as well as an increased level of stress in the legumes. Imazathepyr and flumetsulam were tolerated better under the wet conditions in 1992 when compared to the other herbicides tested. There was little difference in response of the sub-clovers and polymorpha medics to 2,4-DB and the diuron + 2,4-DB mixture which suggests that the cheaper mixture can be favoured over the 2,4-DB alone. Notable species differences were the sensitive response of the medics to terbutryne + MCPA and the higher safety of the barrel medics to 2,4-DB.

Seed yields did not necessarily correspond with the reductions in biomass at anthesis. Many herbicide by variety combinations showed no significant reduction in seed yields even when biomass reductions occurred (Table 2). While seed yields were available for both years for only the polymorpha medics, the changes in seed yields induced by herbicides were consistent over two quite dissimilar seasons. The barrel medics and two of the polymorpha medics showed clear intolerance to terbutryne + MCPA, while Serena showed intolerance to 2,4-DB. Diflufenican, imazathepyr and flumetsulam all caused substantial seed yield reductions on Nungarin.

These results show that the individual species of pasture legumes and the varieties within a species all exhibited differential reaction to broad-leaved herbicides. This agrees with results published elsewhere (2, 3). This differential tolerance could be shown as morphological abnormalities, biomass reductions, and most importantly for Western Australia, as seed yield reductions. Pasture legumes fill a number of roles within the ley farming system including grazing of herbage over the winter/spring, seed for grazing over summer, nitrogen input for subsequent cereal crops and seed production for pasture regeneration. Large reductions in biomass or seed production can negatively affect the roles played by pasture legumes in the system. Providing information on the relative tolerance of varieties to herbicides enables choices to be made which may increase the viability and profitability of the system.

Table 1. Biomass scores at flowering of 8 pasture legumes treated at the 3-5 leaf stage.

Treatment (rate/ha)	Dalk[a]	Nung	Sere	Sant	C.V.	Cypr	Para	Orion
2,4-DB (1.5 kg)	4.9[b]	3.1	2.1	4.4	3.9	-	-	-
	6.4	5.9	6.5	8.2	7.6	5.5	3.3	9.1
Diuron + 2,4-DB	3.4	3.1	2.6	4.4	3.1	-	-	-
(0.1 kg + 0.2 kg)	5.9	5.4	6.8	7.7	7.4	7.3	4.6	4.8
Terbutryne + MCPA	-	-	-	-	-	-	-	-
(0.275 kg + 0.16 kg)	7.4	6.9	9.0	9.4	9.4	10.0	9.8	9.8
Diflufenican (0.1 kg)	5.7	4.4	4.6	4.7	3.6	-	-	-
	3.2	7.2	4.0	3.9	5.9	8.0	5.1	5.1
Bromoxynil + diflufenican	4.4	3.1	4.6	5.9	3.4	-	-	-
(62.5 g + 6.25 g)	4.2	2.1	7.0	7.9	6.9	7.0	3.1	5.1
Imazathepyr (37.5 g)	-	-	-	-	-	-	-	-
	1.2	2.5	2.0	4.9	3.4	2.0	2.1	1.6
Diuron + imazathepyr	4.7	3.4	3.1	4.2	3.4	-	-	-
(0.15 kg + 37.5 g)	6.4	6.4	7.0	6.7	6.2	6.0	4.8	3.6
Flumetsulam (40 g)	-	-	-	-	-	-	-	-
	2.7	2.6	3.7	2.2	2.4	2.0	0.6	2.1
l.s.d. (p = 0.05)	2.4	2.3	2.1	2.2	2.4	-	-	-
	1.2	2.2	1.8	2.1	2.2	2.1	2.0	1.7

[a] Varieties within each species
Trifolium subterraneum - Dalk = Dalkeith, Nung = Nungarin
Medicago polymorpha - Sere = Serena, Sant = Santiago, C. V. = Circle Valley.
Medicago truncatula - Cypr = Cyprus, Para = Parabinga
Medicago sphaerocarpos - Orion

[b] Values for 1991 and 1992 respectively within each variety. - indicates variety not tested for that herbicide in 1991.

These results also highlight the need for further work on pasture legume tolerance to ensure that herbicide labels provide correct information to farmers. New legume species continue to be introduced and in some cases labels do not clearly define the species for which a herbicide is safe. For example, some labels indicate that a herbicide may be used on clover or medics. As the number of commercial species of medic is now over 10, and new herbicides are likely to be introduced for pasture legumes in the future, such a label statement leaves both the farmer and chemical company open to potential problems if no clear statement is made of the herbicide tolerance of the various species and varieties of pasture legumes.

Table 2. Seed yields (as percent of untreated) of 8 pasture legumes treated at the 3-5 leaf stage

Treatment (rate/ha)	Dalk	Nung	Sere	Sant	C.V.	Cypr	Para	Orion
Untreated yield (kg/ha)	-	-	600	601	310	-	-	-
	662	463	909	1193	612	540	448	227
2, 4-DB (1.5 kg)	-	-	66	91	118	-	-	-
	74	92	49	79	95	152	130	80
Diuron + 2, 4-D	-	-	77	94	106	-	-	-
(0.1 kg + 0.2 kg)	83	97	104	86	103	82	148	208
Terbutryne + MCPA	-	-	-	-	-	-	-	-
(0.275 kg + 0.16 kg)	106	107	42	24	73	5	21	67
Diflufenican (0.1 kg)	-	-	68	103	116	-	-	-
	160	48	70	137	116	87	177	199
Bromoxynil + diflufenican	-	-	64	93	109	-	-	-
(62.5 g + 6.25 g)	110	75	73	47	109	134	114	137
Imazathepyr (37.5 g)	-	-	-	-	-	-	-	-
	125	48	120	100	124	75	132	104
Diuron + imazathepyr	-	-	109	124	107	-	-	-
(0.15 kg + 37.5 g)	107	88	75	119	124	137	159	170
Flumetsulam (40 g)	-	-	-	-	-	-	-	-
	146	52	76	116	129	143	154	174
l.s.d. as per cent of untreated	-	-	31	37	33	-	-	-
(p = 0.10)	29	43	40	29	38	63	48	76

[a] Varieties within each species
Trifolium subterraneum - Dalk = Dalkeith, Nung = Nungarin
Medicago polymorpha - Sere = Serena, Sant = Santiago, C. V. = Circle Valley.
Medicago truncatula - Cypr = Cyprus, Para = Parabinga
Medicago sphaerocarpos - Orion

[b] Values for 1991 and 1992 respectively within each variety. - indicates variety not tested for that herbicide in 1991.

Most research on pasture legume tolerance to herbicides is also done in the absence of grazing. Such an issue needs to be addressed in future research in order to better understand how legumes that have been damaged by herbicides early in their growth may compensate for that damage. Given that some herbicides such as 2,4-DB and imazathepyr can, apparently, still produce morphological effects as late as flowering on some varieties, the interactions with grazing may be of some importance in considering legume safety.

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THE EVALUATION OF HERBICIDES AND APPLICATION TECHNIQUES FOR THE CONTROL OF ST JOHN'S WORT (*HYPERICUM PERFORATUM* VAR. *ANGUSTIFOLIUM*) IN GRAZING AREAS OF NEW SOUTH WALES

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Summary. Three replicated herbicide trials were conducted on steep grazing country heavily infested with St John's wort in NSW from 1989 to 1991. The trials evaluated a range of herbicide products and rates using the high volume spray application technique. A proprietary formulation of triclopyr (butoxyethyl ester) and picloram (hexoxy propylamine salt) @ 150 g a.i. + 50 g a.i./100 L water was applied as a high volume spray (3,000 L/ha) produced the highest control of St John's wort, after 36 m months at Cassilis, 21 months at Rouchel and 14 months at Bundella.

INTRODUCTION

St John's wort, *Hypericum perforatum* var. *angustifolium*, brought into Australia in 1875 as a garden plant, in now a widespread weed of pastures. It causes photosensitisation in sheep, cattle, horses and goats, resulting in loss of condition, lower productivity and, in extreme cases, death. It also spoils fleece quality by adding vegetable fault to wool, and excludes useful plants from pastures (2).

St John's wort is spreading at an alarming rate in grazing hill country in the slopes and tablelands areas of NSW and over 250,000 ha in NSW are estimated to be infested with St John's wort.

METHODS

Trial 1 was located at Cassilis, Upper Hunter Valley, with Trial 2 located at Upper Rouchel, Hunter Valley, and Trial 3 was located at Bundella, Liverpool Range, NSW. A randomised complete block design with three replicates was used.

Trial 1 had a dense stand of St Johns wort, growing on steep, basalt hill country. The wort was 50-60 cm tall of an average density of 50% groundcover. Plants actively growing at mid flowering stage, with 40% of plants displaying yellow, open flowers and 60% brown pod stage. Plot size was 3x5 m and herbicides were applied on the 19 December 1989 using a Silvan ATV Flojet Spray Unit fitted with a variable spray nozzle handgun operating at a pressure of 450 kpa and generally applying 2,000 or 3,000 L/ha depending on herbicide used.

Trial 2 had an even dense stand of St John's wort, 75-90 cm high with 65% brown pods when sprayed at the late flowering stage on 23 January 1991. Plot size was 2x5 m and treatments were applied with a Solo knapsack sprayer fitted with a variable spray nozzle. Spray volumes of 3,000 L/ha and 1,500 L/ha were compared.

Trial 3 also had an even stand of wort which was sprayed at two growth stages, pre-flowering under good growth conditions and flowering under moisture stress. Plot size was 5x10 m and treatments were applied with a power operated sprayer using a handgun fitted with a D6 tip and operating at a pressure of 500 kPa. The fine droplets produced were applied in successive vertical sweeping motions up and down each plant, wetting both leaves and stems.

Formulations tested included Grazon DS# (300 g a.i./L triclopyr as butoxyethyl ester and 100 g a.i./L picloram as hexoxy propylamine salt), Garlon 600# (600 g a.i./L triclopyr as butoxyethyl ester) and Tordon 50-D# (200 g a.i./L 2,4-D and 50 g a.i./L picloram, both present as the tri-isopropolamine salt), Roundup^ (360 g a.i./L glyphosate as the isopropylamine salt) and Brushoff* (600 g a.i./kg metsulfuron methyl). Agral 600 surfactant at 0.1% v/v was added, where label recommendations required, with Ulvapron~ @ 0.1% v/v added to some treatments. Plots were visually rated for percent control the following seasons.

RESULTS AND DISCUSSION

In all trials, picloram+tricloyr provided effective control of St John's wort when applied under good growing conditions, between October and January and the results are shown in Tables 1 to 4.

Table 1. Percent control of St Johns wort using high volume application technique at Cassilis 12, 24 and 36 MAA (months after application)

Treatment	Rate (g/100 L)	Spray volume (L water/ha)	Percent control		
			12 MAA	24 MAA	36 MAA
picloram+triclopyr	25 + 75	3,000	99	94	86
picloram+triclopyr	50 + 100	3,000	100	99	94
triclopyr	102	3,000	76	68	40
picloram+2,4-D	25 + 100	3,000	76	79	58
glyphosate	180	2,000	84	68	61
glyphosate	360	2,000	88	72	75
metsulfuron methyl	6	2,000	90	83	75

Table 2. Percent control of St John's wort using high volume application technique @ 3,000 L water/ha, with and without the addition of Ulvapron Spray oil @ 0.1% v/v at Rouchel 12 and 21 MAA (months after application).

Treatment	Rate (g/100 L)	Without oil		With oil	
		12 MAA	21 MAA	12 MAA	21 MAA
picloram+triclopyr	12.5 + 37.5	67	68	69	73
picloram+triclopyr	25 + 75	81	87	83	93
picloram+tricopyr	50 + 150	100	99	100	100
triclopyr	102	53	53	46	40
picloram+2,4-D	25 + 100	81	82	88	87
picloram+2,4-D	50 + 200	92	97	94	99

Registered trademark of DowElanco.
^ Registered trademark of Monsanto Australia Ltd.
* Registered trademark of DuPont.
~ Registered trademark of BP Australia Ltd.

This trial clearly identified picloram+triclopyr as the most effective herbicide treatment on St Johns wort 12, 24 and 36 months after application. Picloram+triclopyr at 50+150 g/100 L was the most reliable treatment, showing better control than currently registered ingredients triclopyr, picloram+2,4-D and glyphosate.

The addition of oil (Ulvapron) at 0.1% v/v to picloram+triclopyr slightly improved the control of St John's wort (not significant), however, the level of control with triclopyr was reduced by the addition of oil, as shown in Table 2.

Spray volume did not significantly affect control of St John's wort with picloram+triclopyr, when applied at equivalent rates/ha and these results are shown in Table 3.

Table 3. Percent control of St John's wort following high volume application of picloram+triclopyr at different application volumes, Rouchel, 12 and 21 MAA (months after application)

Treatment	Rate (g/100 L)	Spray volume (L/ha)			
		3,000		1,500	
		12 MAA	21 MAA	12 MAA	21 MAA
Picloram + triclopyr	0.375 + 1.125	67	68	66	70
Picloram + triclopyr	0.75 + 2.25	87	87	77	80

Even though there was no significant difference between control of St John's wort with picloram+triclopyr at different application volumes, it was much easier to calibrate the application technique to apply 3,000 L/ha compared to 1,500 L/ha. There was less likelihood of application errors applying 3,000 L/ha, as it was essential to obtain complete coverage of the whole plant to obtain acceptable results.

Table 4. The effect of dry conditions on the control of St John's wort with picloram+triclopyr and picloram+2,4-D by high volume application at Bundella

Treatment	Rate (g/100 L)	Time 1 Application: 4.10.91 Stage: pre-flower Soil Moisture: good Plants active growth	Time 2 Application: 3.12.91 Stage: flowering Soil Moisture: poor Plants stressed
		% control 14 MAA	% control 12 MAA
picloram+triclopyr	50 + 150	92	82
picloram+triclopyr	35 + 105	-	67
picloram+triclopyr	25 + 75	78	47
picloram+2,4-D	50 + 200	93	80
picloram+2,4-D	25 + 100	80	40

Results in Table 4 show lower control of St John's wort after application of picloram+triclopyr and picloram+2,4-D to flowering plants under poor soil moisture conditions, when plants were stressed. Results show that best control of St John's wort was achieved with picloram+triclopyr at 50+150 g/100 L water in a spray volume of 3,000 L/ha, applied when good soil moisture was present and plants were actively growing from pre-flowering to flowering or November to January.

Although not reported in this paper, other application techniques have been evaluated during our research, which included Dupont Gas Gun, aerial application by helicopter and boomspray techniques. All trials confirm that picloram+triclopyr at 1.5+4.5 kg/ha was required to achieve effective control of St John's wort by all application methods.

From these results Ross Watson, District Agronomist Scone (3) obtained a pesticide order issued on 18 March 1992 for the use of picloram+triclopyr (Grazon DS @ 500 mL/100 L water) for the control of St John's wort, with the following critical comments:-

1. Apply during late spring to early summer (Nov-Jan) to coincide with flowering to early seed set. Do not apply during the autumn or winter as inferior levels of control will occur.

2. High Volume: apply through well calibrated hand gun equipment. Adjust hand gun spray equipment to apply the equivalent of 3,000 L/ha (ie. 3 L/10 square m). Check your application rate over a measured area of St John's wort infestation before spraying large areas. Adjust hand spraying speed or nozzle size to change application rate. Always ensure thorough coverage.

3. Handgun equipment should be fitted with a D5 (2 mm) nozzle plated and operated at 400-500 kPa as a broad spray pattern. Apply to thoroughly wet all leaves and stems, avoiding excess runoff. Do not apply to plants showing obvious signs of stress. If applied as directed, one application will provide a high degree of control. Some minor regrowth and seedlings may need retreatment the following summer. Grasses are largely unaffected, pasture legumes are severely damaged or killed by this herbicide. Clover regeneration will be significantly reduced for 12-18 months after application. However, good regeneration from seed should be observed 18-24 months after application (1).

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THE EFFECT OF PASTURE DENSITY AND COMPOSITION ON VULPIA

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Summary. A field experiment was conducted at Wagga Wagga in southern New South Wales, Australia to quantify the effects of subterranean clover, *Trifolium subterraneum*, density and pasture composition on the seed production and regeneration of vulpia, *Vulpia bromoides*. Increasing the density of subterranean clover from 140 to 1,800 plants/m^2 substantially reduced the reproductive capacity of vulpia in the first year, but by the third year of the experiment there was no difference between treatments. A mixture of subterranean clover and annual ryegrass, *Lolium rigidum*, significantly reduced seed production (*cf.* various densities of subterranean clover alone) and subsequent regeneration and establishment of vulpia throughout the three years of the experiment. The results show that the inclusion of a companion grass (in this case annual ryegrass) was necessary to maintain the vulpia content of pastures at a low level.

INTRODUCTION

Vulpia, *Vulpia bromoides* and *V. myuros*, is a common component of subterranean clover, *Trifolium subterraneum*, based pastures throughout southern Australia where it reduces productivity, contaminates wool, injures livestock, and helps carryover pathogenic fungi such as *Gaeumannomyces graminis* var. *tritici* from one crop phase to the next. As a result of a farm survey which suggested an inverse relationship between the incidence of vulpia and competition from other pasture plants (1), a field experiment was conducted at Wagga Wagga in southern New South Wales to quantify the effects of pasture density and pasture composition on the build-up of vulpia.

METHODS

Four pastures [three subterranean clover (SC) densities and one subterranean clover plus annual ryegrass mixture (SC+RG)] were established on a medium textured red-brown earth soil at Wagga Wagga. Each of the pasture treatments were sown with two densities of vulpia, *V. bromoides*, and with (high fertility) and without (low fertility) the addition of lime and fertiliser. In the high fertility treatment lime and fertilizer rates were chosen to ensure soil fertility was not limiting subterranean clover growth. Lime (1.75 t/ha) and a range of fertilizers were applied and incorporated into the soil one week before pastures were sown on 21 May 1990. Molybdenum superphosphate (400 kg/ha) and disodium tetraborate (7 kg/ha) were hand broadcast, while copper sulphate (15 kg/ha), and zinc sulphate (15 kg/ha) were applied by boom sprayer. Molybdenum superphosphate (400 kg/ha) was re-applied every year just after sampling for soil analyses in early autumn. At the start of the experiment the site had a pH of 4.6 ($CaCl_2$) and 7 *ug* P/g soil (Olsen method). When sampled in March 1992, the addition of lime had increased the pH to 5.4 and the addition of superphosphate had increased the soil phosphate level to 12 *ug* P/g soil.

Low, medium, and high SC densities were obtained by sowing 1, 25, and 100 kg/ha SC cv. Junee in small plots (2x6 m^2) on 21 May 1990. The SC+RG mixture was established by sowing

25 kg/ha SC plus 20 kg/ha RG. The layout was a split-plot design (2 fertility levels as the main plots, with the 4 pastures x 2 vulpia densities fully randomised within each fertility level) replicated 4 times.

Plant densities were determined by counting all plants in 20 cores (4.5 cm diam.) taken at random from each plot in August 1990 and 1991, and in late May 1992. Early counting was necessary in 1992 because in June half the plots were sprayed with simazine to continue another experiment.

Panicle densities were determined by counting all panicles in 10 quadrats (7.5 cm x 7.5 cm) harvested at maturity each year. To determine seed production 50 panicles were randomly selected from those harvested for panicle measurements. All spikelets on each of the 50 selected panicles were counted and the average number of spikelets per panicle calculated for each plot. A sub-sample of 10 panicles were randomly selected for estimating seeds per spikelet. Viable seeds were counted in three randomly selected spikelets on each of the 10 panicles, and the average number of seeds per spikelet calculated for each plot. Seed production for each plot was then calculated by multiplying panicles/m^2 x spikelets/panicle x seeds/spikelet.

RESULTS AND DISCUSSION

Averaged over all pasture treatments and fertility levels, 240 and 1,140 vulpia plants/m^2 had established by August 1990 in the low and high vulpia treatments, respectively. Vulpia seed production and plant densities varied with season and pasture treatment, but were not affected by fertility, and eventually numbers for the two vulpia sowing rates were similar. For these reasons the data presented are the means of both fertility levels and both vulpia sowing rates.

The results obtained for vulpia plant density and seed production in 1990 and 1991 and subsequent regeneration in 1992 are presented in Table 1. Compared with the low SC density, the medium and high SC densities reduced vulpia seed production in 1990 by 50 and 78%, respectively. Similar results were obtained for regeneration of plants in 1991 (reductions of 41 and 61%, respectively).

The mixed SC+RG pasture had the greatest effect on vulpia, reducing seed production in 1990 by 83%, and establishment of plants in 1991 by 81%, when compared with the low SC density.

Increasing the density of subterranean clover had no effect on seed produduction of vulpia in 1991. The regeneration of vulpia in 1992 was also unaffected by subterranean clover density. However, the inclusion of annual ryegrass in the sward continued to restrict ingress by vulpia. The SC+RG treatment reduced seed production in 1991 by 60%, and regeneration of vulpia in 1992 by 73%.

Increasing the density of subterranean clover substantially reduced the reproductive capacity of vulpia in 1990, but by 1992 there was no difference between treatments. These results show that vulpia very quickly invades subterranean clover pastures, even when growing in dense stands (mean subterranean clover densities in 1991 were: 1,102, 2,827, and 3,904 plants/m^2 in the low, medium, and high subterranean clover density treatments, respectively). The inclusion of a companion grass (in this case annual ryegrass) was necessary to reduce the growth and seed production, and subsequent regeneration of vulpia. This supports the results obtained from the farm survey (1) which showed that vulpia densities were least where pastures contained a significant grass component.

Table 1. Effect of pasture density and composition on vulpia invasion in pastures sown at Wagga Wagga in 1990

Pasture density and/or composition	Vulpia plant density and seed production/m^2				
	1990		1991		1992
	Plants	Seeds	Plants	Seeds	Plants
Low sub clover density	720	1,071,300	22,610	432,000	9,200
Med sub clover density	860	536,200	13,370	399,700	7,700
High sub clover density	550	239,300	8,890	386,100	9,720
Sub clover + rye grass	640	179,400	4,290	173,300	2,530

ACKNOWLEDGMENTS

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MANAGEMENT PRACTICES ASSOCIATED WITH INCREASE OF VULPIA IN PASTURES - A SURVEY

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Summary. A survey of 49 farms from central and southern New South Wales Australia was undertaken in 1989 to identify factors responsible for the increase in incidence of vulpia in pastures. Reduced competition from other pasture plants was the main explanation given by farmers for this increase and this was confirmed by measurements taken from sample paddocks. Reasons for lack of competition differed with location (cropping zone or permanent pasture zone). Results suggest that long-term management of vulpia in pastures will involve the maintainence of a significant proportion of other competitive species in the sward.

INTRODUCTION

Vulpia, or silver grass, is a small, fine-leaved annual grass which occurs as a naturalised volunteer in most Australian temperate and Mediterranean pastures (4). It is an abundant weed of improved pastures in all regions of southern and central NSW, and is also a major problem on the Northern Tablelands and the South Coast, and in much of Victoria, South Australia, and Western Australia. Vulpia reduces profitability from pastures by contaminating the wool of grazing sheep, producing less winter forage than other annual grasses, and in late winter and spring, producing feed of low palatability. Results from various surveys indicate that many pastures contain >50% vulpia ((2); Leys and Dowling, unpublished data) indicating that voluntary intake in these situations is likely to be reduced. In addition, vulpia residues are low in nutritive value (3) providing a poor source of feed over summer.

METHODS

Forty nine farms from central and southern New South Wales were surveyed during October and December 1989. The survey involved an interview with each farmer to complete a questionnaire on farm management practices from two sample paddocks per farm. Detailed measurements of soil characteristics, pasture composition and the occurrence and density of vulpia species were also made in each sample paddock.

<u>Farm selection</u>. Farms were selected from two zones in central and southern New South Wales. Twenty seven farms were selected from the winter cropping zone of the western slopes between the 500 and 650 mm isohyets, and 22 farms were selected from pastoral areas of the tablelands between the 650 and 800 mm isohyets. Farms were selected from throughout each zone by NSW Agriculture District Agronomists. Four criteria were used to select the farms:

a. Only farms on which vulpia was known to be a problem were included;
b. The farm was at least 200 ha;
c. The farmer had been owner/manager for at least 5 years and kept good paddock records;
d. Only 2 to 4 farms were selected from any one Agronomy District, the aim being to have an even distribution of farms from Dubbo/Merriwa in the north to the Victorian border.

Paddock selection. Two paddocks were selected from each farm. Paddock 1 had a high incidence of vulpia, while Paddock 2 was nearby but had much less vulpia. Both paddocks had to be at least 10 ha (this eliminated small special purpose paddocks), and sown to pasture species for at least 2 years.

Pasture assessments. A uniform patch of vulpia (>50 m diameter), representative of the paddock, was selected in each sample paddock for soil and pasture sampling. Total pasture dry weight and botanical composition were estimated by the ranking method of 'T Mannetje and Haydock (1963). Vulpia plant densities were estimated by counting all plants in 30x4.5 cm diameter cores sampled in a W pattern from within the selected patch. Panicle densities were estimated by counting all vulpia panicles in 10 quadrats (7.5x7.5 cm) samples in a W pattern from within the patch. Thirty of these panicles were randomly selected to determine the proportion of each vulpia species in the sward.

Soil characteristics. Twenty soil cores (4.5 cm diameter by 7.5 cm deep) were randomly sampled from each vulpia patch. A sub-sample was removed to determine soil texture and the remainder was dried at 40°C for 48 h before grinding to pass a 2 mm sieve. A sub-sample was used to determine pH, organic matter, total exchangeable cations, total soil nitrogen, and soil phosphorus.

RESULTS

Most farmers suggested a general deterioration of pastures as the main reason for the widespread abundance of vulpia. This was reflected in the rankings given to the factors responsible for the greater prevalence of vulpia in Paddock 1 (*cf.* Paddock 2; Table 1).

In the cropping zone, 89% of farmers ranked "less vigorous pastures" one of the top 3 reasons for the greater prevalence of vulpia in Paddock 1. This was more than double the score for any other factor. Other reasons which ranked highly were: lower soil fertility (41%); lower soil pH (37%); and greater use of herbicides which removed competing species (37%). The herbicides responsible were diclofop-methyl (most frequently mentioned because of its widespread use for control of annual ryegrass during the 1980's), fluazifop-P (reduces the density of a range of annual grasses but not vulpia), and herbicides for broad-leaved weed control (reduced the density of broad-leaved weeds such as Paterson's curse). All of these factors reduce the ability of pastures to compete with vulpia, thus allowing it to invade more readily.

In the pastoral zone, 68% of farmers ranked "less vigorous pastures" one of the top 3 factors responsible for the greater prevalence of vulpia in Paddock 1. As in the cropping zone, other reasons which ranked highly were lower soil fertility (41%) and lower soil pH (41%). The occurrence of droughts was also thought to contribute to the higher incidence of vulpia (41%). Droughts would also reduce the density of pastures in Paddock 2, and although some of the pastures in this second paddock have been replanted after the major drought in 1982-83, the average age of pastures in the two paddocks were similar (8.2 and 7.8 years in Paddocks 1 and 2, respectively). Thus, the reliability of the rankings given to this factor is questionable.

In the pastoral zone, herbicide use did not rate among the top 3 factors affecting vulpia. This contrasts with the cropping zone where it had a relatively high ranking. Cultivation was the only other factor which farmers thought contributed to greater prevalence of vulpia. Twenty two percent of farmers in the cropping zone, and 18% of farmers in the pastoral zone, considered less cultivation, especially less use of disc implements, to have contributed to the difference in vulpia levels in the two paddocks.

Table 1. Factors responsible, and the percentage of farmers who ranked them as one of the top three causes, for the greater prevalence of vulpia in Paddock 1 compared with Paddock 2[a,b]

Factors	Cropping zone	Permanent pasture zone
Less vigorous pasture	89	68
Lower soil fertility	41	41
Lower soil pH	37	41
Greater use of herbicides which reduced competition from other species	37	0
Droughts which reduced the persistence of sown species	7	41
Less cultivation	22	18
Different stocking rate	7	9
Different agronomic practice	0	0
Different livestock practice	0	0
Other	0	5

[a] Paddock 1 = dense vulpia; Paddock 2 = less vulpia)
[b] Percentage of farmers who ranked each factor as 1, 2, or 3 (where 1 = most likely cause for the greater prevalence of vulpia in Paddock 1 than Paddock 2)

Our measurements of soil characteristics, pasture composition, and various parameters of vulpia abundance taken in the sample paddocks, confirm the farmers' opinions that lack of pasture competition is the main reason for the greater prevalence of vulpia in pastures. In the cropping zone vulpia was four times more abundant in Paddock 1 than Paddock 2, while in the pastoral zone there was a 3.5 fold difference in the vulpia content (as measured by plant density, panicle density, or percentage DW; Table 2).

The incidence of vulpia is inversely correlated with the proportion of other pasture species, especially annual, or perennial grasses. This was most obvious in the pastoral zone where annual grasses comprised 4 and 14%, and perennial grasses 16 and 39% of the total DW of the pastures in Paddocks 1 and 2, respectively, while the corresponding vulpia contents were 49 and 14%. Similar, but less pronounced effects, occured in the cropping zone. However, in this zone an increase in the legume component (from 32% in Paddock 1 to 54% in Paddock 2) may have been just as important as an increase in the grass component.

Soil pH, soil P, and total soil N levels were similar in the two sample paddocks and probably only indirectly influence vulpia through their effect on pasture vigour (Table 2). In both zones OM and CEC levels in the soil were slightly higher in Paddock 2 than Paddock 1.

Although there are at least five species of vulpia in Australia, *V. bromoides*, is by far the most prevalent in southern and central New South Wales (73% of the sward in the cropping zone, and 76% of the sward in the pastoral zone - similar to a previous survey (1)). *V. myuros* was the only other species of any consequence (26% of the sward in the cropping zone, and 24% of the sward in the pastoral zone). *V. muralis* occurred as a very minor component in the western part of the cropping zone in central New South Wales, while *V. ciliata* and *V. fasciculata* were not recorded.

Table 2. Mean abundance of vulpia, soil characteristics, and pasture composition in the two sample paddocks from the cropping zone and the pastoral zone[a]

Parameter	Cropping zone		Pastoral zone	
	Paddock 1	Paddock 2	Paddock 1	Paddock 2
Vulpia abundance				
Plant density (plants/m^2)	4,289	1,054	7,325	2,110
Panicle density (panicles/m^2	5,928	1,223	10,485	3,235
Vulpia DW (% of total DW)	48	12	49	14
Soil characteristics				
Soil pH	4.5	4.6	4.4	4.5
Soil P (ug/g)	9.7	9.9	12.0	10.3
Total soil N (%)	0.11	0.13	0.17	0.18
Soil OM (%)	1.84	2.16	2.94	3.06
CEC (cmol(+)/kg)	5.4	6.4	4.8	6.4
Botanical composition				
Other annual grasses (% of total DW)	12	25	4	14
Perennial grasses (% of total DW)	1	5	16	39
Pasture legume content (% of total DW)	32	54	22	27

[a] Paddock 1 = dense vulpia; Paddock 2 = less vulpia)

The results of both the personal interviews with the farmers, and measurements taken from the sample paddocks, suggest that the abundance of vulpia is least where pastures contain a significant grass component. For example, in Paddock 2 pastures in the cropping zone contained 30% grass, while those in the pastoral zone contained 53% grass. However, it is impossible to conclude from the survey alone, whether the higher grass content of pastures in Paddock 2 was the cause, or the effect, of the lower vulpia content.

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TOWARDS SAFER AND MORE EFFICIENT USE OF RESIDUAL HERBICIDES IN THE NORTH-EASTERN GRAIN REGION OF AUSTRALIA

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Summary. This group of agronomists and pesticide chemists is investigating the influence of soil factors on persistence, movement and activity of atrazine and chlorsulfuron, the responses of crops and weeds to their residues, and the long-term effects in the soil after repeated applications of these residual herbicides. Persistence increased with soil pH and clay content, activity decreased with clay content, and residues were mostly in the surface 10 cm for atrazine and 20 cm for chlorsulfuron. Crop damage increased with herbicide concentration in the root zone in both soil-free systems and the field. Only small levels of residues have been detected in the soil profile following repeated use, and these residues were confined to the surface 50 cm.

INTRODUCTION

The residual herbicides atrazine and chlorsulfuron provide cost-effective and long-term weed control in crops and, to a lesser extent, in fallows in the north-eastern grain region. However, more efficient use of these herbicides is being hampered by their variable field performances and persistence in the different environments, and by the conservative re-cropping intervals. Also, farmers and the general public are expressing concerns about the fate of herbicides in the farming environment.

The authors are addressing these problems by investigating the following aspects of atrazine and chlorsulfuron: the influence of soil factors on persistence, movement, and activity; the sensitivity of crops and weeds to residue levels; the relationship between crop response in the field, and measured crop sensitivity and residue levels in the root zone; and the long-term effects in soils after repeated herbicide application. Whilst some of this research is still in progress, we present an overview of current findings in this paper, and certain aspects in more detail in two posters (2,5) and another paper (3).

METHODS

Degradation rates of atrazine and chlorsulfuron were measured in a range of treated agricultural soils of southern Queensland that were incubated at constant 25°C and field capacity. Subsequently, persistence of these herbicides was measured in soils in the glasshouse and in the field. Persistence of 2,4-D amine and glyphosate has also been measured at several field sites (4).

Distribution of atrazine and chlorsulfuron in the soil profile was measured at several sites and seasons in southern and central Queensland. Soil type ranged from red brown earth to black earth.

Initial activity in 26 agricultural soils, mainly grey clays and black earths, was determined by measuring ID_{50}, the dose required for 50% inhibition of seedling growth of ryegrass (*Lolium rigidum*) in controlled environment cabinets. The measured differences in initial activity of both herbicides are being verified for six of the 26 soils using a range of annual weeds grown in the glasshouse.

Relationships between plant growth and herbicide concentration in the root zone are being determined in a soil-free system in the glasshouse and in black earths in southern and central Queensland. Crop response in the soil-free system is covered in more detail in the conference paper by Jettner *et al.* (3).

The persistence and distribution of residues were measured in a red brown earth following the application of 140 g chlorsulfuron/ha and 20.5 kg atrazine/ha in eight sprayings since 1983.

Total and water extractable atrazine residues were measured using HPLC with minimum detection level of 0.002 µg/g soil. Residue levels of chlorsulfuron in the field were measured using a bioassay based on the suppression of maize root length. Minimum detection level with the bioassay was 0.1 ng/g soil. The HPLC was used to measure the degradation rates of chlorsulfuron in the incubated soils that were treated with high doses of the herbicide.

RESULTS AND DISCUSSION

Persistence. Half-life of atrazine and chlorsulfuron in the incubated soils ranged from 23 and 10 days in a red brown earth (pH 5.3) to 149 and 109 days in a black earth (pH 8.7) respectively. Soil pH and clay content were the main soil properties influencing atrazine persistence, and together they accounted for 89% of the half-life variation in 12 soils. Soil pH alone accounted for 96% of the variations in chlorsulfuron half-lives in five soils. Persistence of atrazine and chlorsulfuron followed similar trends in soils subjected to fluctuating temperatures and water contents in the glasshouse and field as in the incubated soils. In southern Queensland the half-life of atrazine was 45 days in a red brown earth (pH 7.9) following a December application, and was approximately 60 days for chlorsulfuron following a June application. Persistence in central Queensland was much less due to the higher soil temperatures. Preliminary comparisons between the measured field persistence and that predicted by a computer simulation model (1) with our soil parameters were similar.

Movement. The majority of residues remained within the seedling root zone. Within six months of herbicide applications in different field sites, 85-100% of atrazine residues were in the surface 10 cm and 63-100% of chlorsulfuron residues were in the surface 20 cm. No residues were detected below 50 cm, indicating that these herbicides are unlikely to leach down the soil profile into our groundwater in these environments.

Activity. Although the ID_{50}'s varied greatly between the different soils (ranging from 2.4 to 54.0 ng/g for chlorsulfuron and from 0.5 to 1.8 ug/g for atrazine), the mean ID_{50}'s in black earths were at least double that in grey clays. The main reason for the greater activity in grey clays was lower clay content, although the correlations were not strong (r = 0.5-0.6). Atrazine activity was strongly related to the adsorption coefficient (Kd) and to the proportion of water extractable residues (r = 0.9). These measured differences in activity were evident also for a range of major weeds growing under glasshouse conditions.

Crop and weed response. The sensitivity of major crops (3) and some weeds to atrazine and chlorsulfuron residues that are fully available to the whole root system is being determined . As an example, the atrazine ID_{50} for the more susceptible weed mintweed (*Salvia reflexa*) was 0.03 µg/mL compared with 0.06 µg/mL for barnyard grass (*Echinochloa colona*).

In the field, crop responses to fallow applications of atrazine and chlorsulfuron have varied with seasons and sites. In the hot and often dry conditions of central Queensland, sorghum and sunflowers were sown safely four months after application of 30 g chlorsulfuron/ha. However, sufficient residues of atrazine persisted sometimes to damage sunflowers and wheat sown 4 and seven months respectively after applications of rates as low as 500 g/ha. In southern Queensland the order of increasing phytotoxicity to atrazine in winter was chickpeas, barley, and wheat, and to atrazine in summer was maize, sorghum, soybeans, cotton, and sunflowers.

The differences in crop responses between seasons and sites were related to the concentration of plant-available herbicide in the root zone at sowing. As an example, wheat seedlings were adversely affected only in plots with concentration of water extractable atrazine greater than 0.02 µg/g in the 5-10 cm depth. This is in agreement with the crop sensitivity data. These critical levels need to be predicted or measured accurately in the field for safe re-cropping. We have evaluated test-kits (2) and will be evaluating further a computer simulation model (1) using our derived parameters for herbicide persistence and availability. The model will be used for predicting the length of weed control for different environments using the weed sensitivity data.

Long-term studies. Only 50 g atrazine/ha and 1 g chlorsulfuron/ha were detected at 12 months after the eighth annual applications of atrazine in sorghum and chlorsulfuron in wheat in a red brown earth (pH 7.9). These remaining residues are less than 1% of the total amount applied, indicating that atrazine and chlorsulfuron are unlikely to accumulate in our soils with pH < 8.5 following repeated use.

Conclusions. Significant advances have been made by this group in understanding what happens to the residues of atrazine and chlorsulfuron in the soils of the north-east grain region, and the biological implications of these residues. This will result in increased efficiency of weed control in both fallow and in-crop, and in increased safety and opportunity of re-cropping in this region. Also, the data addresses concerns with the fate of these herbicides in the farm environment.

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MODE OF SAFENING ACTION OF NAPHTHALIC ANHYDRIDE AGAINST INJURY OF SULFONYLUREA AND IMIDAZOLINONE HERBICIDES IN MAIZE

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Summary. Safening action of naphthalic anhydride (NA) in maize, *Zea mays*, treated with sulfonylurea and imidazolinone herbicides and effect of NA and the herbicides on *in vitro* acetolactate synthase (ALS), glutathione S-transferase (GST), and acetyl Co-A carboxylase (ACCase) activities were investigated. NA provided safening factors of approximately 11 and 10 for chlorsulfuron and bensulfuron, respectively, and 5 and 4 for imazaquin and imazethapyr, respectively. NA caused 1.3-, 1.8-, and 3.2-fold increase of ALS, GST, and ACCase activities, respectively. The activities of ALS extracted from both NA-treated and NA-untreated maize were inhibited by bensulfuron and imazaquin. However, the two herbicides did not affect the activities of ACCase obtained from both NA-treated and NA-untreated maize, except for bensulfuron on NA-induced ACCase activity. NA-induced ACCase activity slightly increased with increase in bensulfuron concentration. These results suggested that the safening mode of action of NA might result from multilevel interaction of NA-induced enzyme activities.

INTRODUCTION

The sulfonylurea and imidazolinone herbicides are new families of herbicide introduced in the early 1980s which are highly active at low application rates. The sulfonylureas control a wide range of annual broad-leaved and certain grass weeds in small grain cereals, while the imidazolinones are used for control of annual and perennial grasses and broad-leaved weeds. They can enter plants through roots and foliage and have the same site of action, that is, they inhibit ALS the first enzyme in the synthetic pathways for branched-chain amino acids (9, 10).

Many researches have shown that herbicide safener NA has potential in protecting grass crops from toxicity caused by these herbicides (1, 8). Parker *et al.* (8) demonstrated a reduction in chlorsulfuron activity on maize following NA treatment. Protection of maize against injury from pre-emergence imazaquin application was also achieved by NA treatment of seeds (1).

In a review of mechanisms of safener action, Hatzios (7) indicated that the possible mechanism which receives the most attention is either a safener-induced enhancement of herbicide detoxication or a competitive antagonism of herbicides and safeners at a common target site of action. Based on the suggestion, this study was initiated to evaluate effects of NA on activities of three enzymes related with crop-herbicide-safener combination. The enzymes included were ALS as target site of both sulfonylurea and imidazolinone herbicide action and GST involved in the detoxication of certain herbicides. ACCase was also included since it is a key enzyme in the pathway of fatty acid biosynthesis and the target site of graminaceous herbicides (3, 6).

METHODS

Safening effect of NA. Before planting dressing of maize (cv. 'Suweon 19') seeds with NA was done by shaking in a flask at rate of 0.2% by seed weight. Fifteen seeds of the maize were planted approximately 2 cm deep in a sterilized clay loam soil in 350 cm^2 plastic pots. There were three replications. One day after seeding four herbicides (bensulfuron, chlorsulfuron, imazaquin, and imazethapyr) were soil-applied at rates of 6.25, 12.5, 25, 50, 100, and 200 g/ha. After planting and treatment with the herbicides, the pots were placed in a greenhouse with a 14-h photoperiod and a 30/20°C day/night temperature. All pots were watered from overhead to the soil surface as required. The plants were harvested 21 days after herbicide treatment to measure the fresh weights. On the basis of the results obtained, concentrations of the herbicides causing 50% inhibition (I_{50}) were calculated by probit analysis. Safening factor of NA was then calculated by the ratio of the herbicide concentration giving I_{50} in the presence of NA divided by the herbicide concentration giving I_{50} in the absence of NA (4).

Plant material for enzyme assay. Shoots of 10-day old maize seedlings grown in the conditions as described above were used for ALS and ACCase assays. To obtain etiolated shoots for extraction of GST, maize treated with NA was planted in vermiculite, watered, maintained in a growth chamber in the dark for 3 days at 30°C.

ALS assay. All steps were performed at 4°C unless otherwise noted. Fifty g of the shoots was ground in a mortar prechilled in liquid nitrogen and homogenized in 100 mL of buffer containing 0.1 M K_2HPO_4 (pH 7.5), 5 mM $MgCl_2$ and 10 mM sodium pyruvate. The homogenate was filtered through 8 layers of cheesecloth and centrifuged at 15,000 *g* for 15 min. ALS was precipitated from the supernatant fluid with $(NH_4)_2SO_4$. The enzyme was collected at 65% saturation by centrifugation and the pellet dissolved in the buffer as described above and desalted on Sephadex G-25 (PD-10) equilibrated with the same buffer. The desalted enzyme was used immediately for assay. ALS assay was conducted in a final volume of 2 mL at 30°C. The final reaction mixture consisted of 1 mL of the desalted enzyme, 0.9 mL of 50 mM K_2HPO_4 (pH 7.5) containing 10 mM sodium pyruvate, 0.1 mM thiamine pyrophosphate and 10 mM $MgCl_2$ and 0.1 mL of various concentrations of the herbicides dissolved in acetone. Assay was initiated by adding the pyruvate and terminated by adding 30 µl of 10 N H_2SO_4. ALS activity was determined as described by Westerfeld (11). The acidified reaction mixtures were heated for 15 min at 60°C after which 0.5 mL of 0.5% w/v creatine and 0.5 mL of 5% w/v 1-naphtol dissolved in 10% NaOH were added. The solution was heated for an additional 15 min at 60°C. The absorbance of the solution was then determined at 530 nm. Protein was determined by the method of Bradford (2).

GST assay. Five g of the shoots of etiolated maize seedlings was ground in liquid nitrogen and homogenized in 25 mL of buffer containing 0.1 M K_2HPO_4 (pH 6.8) and 1 mM sodium metabisulfite. The homogenate was filtered through 8 layers of cheesecloth and centrifuged at 20,000 *g* for 20 min. The supernatant was used immediately for assay. GST assay was carried out in a final volume of 2 mL. The reaction mixture contained 0.1 mL of the enzyme extract, 1.9 mL of 100 mM K_2HPO_4 (pH 7.5) and 0.9 mL of 3.3 mM glutathione (reduced form). Assay was initiated by adding 0.1 mL of 30 mM 1-chloro-2,4-dinitrobenzene as the substrate at 25°C. GST activity was measured spectrometrycally at 340 nm for 2 min starting from 1 min after initiation of the reaction.

ACCase assay. Ten g of the plant material was ground in 20 mL of cold extraction buffer containing 0.1 M tricine-KOH (pH 8.0), 10 mM b-mercaptoethanol, 1 mM Na-EDTA and 1 mM phenylmethylsulfonylfluoride. The plant slurry was filtered through 8 layers of cheesecloth and the filtrate was centrifuged at 30,000 *g* for 20 min. The supernatant was used directly for assay. ACCase activity was assayed at 35°C in a 0.2 mL volume which contained 20 mM ATP, 3 mM acetyl CoA, 50 mM $MgCl_2$, 20 mM DTT, 20 mM $NaH^{14}CO_3$ (20 µCi/mmol) and the herbicides. Reactions were initiated by addition of acetyl CoA and stopped by addition of 30 µl of 12 N

HCl. Product formation was determined by the radioactivity found in an acid stable fraction by liquid scintillation spectrometry.

RESULTS AND DISCUSSION

Effect of NA on herbicidal activity. Herbicidal activity of the two groups of herbicides as measured by I_{50} varied with kind of the herbicides used (Table 1). The lowest I_{50} was obtained with chlorsulfuron, whereas I_{50} of bensulfuron and imazethapyr was about 8-fold higher than that of chlorsulfuron. However, no clear difference in I_{50} was found between the two groups. With use of NA I_{50} of the four herbicides increased, indicating safening effect of NA. The safening effect was quantified by safening factor. NA provided safening factors of approximately 10 and 11 for bensulfuron and chlorsulfuron, respectively, and 5 and 4 for imazaquin and imazethapyr, respectively. The safening effect due to NA differed between the two groups of herbicides, but no great difference occurred between the herbicides within the same group. Efficacy of NA in protecting maize from injury of sulfonylurea and imidazolinone herbicides has been reported also by other investigators (1, 8).

Table 1. Herbicide concentration of 50% inhibition and safening factor of combined treatments of NA and sulfonylurea and imidazolinone herbicides on maize

Herbicide	50% Inhibition (g/ha)		Safening factor
	Without NA	With NA	
Bensulfuron	29.1	296.7	10.2
Chlorsulfuron	3.8	42.6	11.2
Imazaquin	7.8	39.5	5.1
Imazathapyr	29.1	116.1	4.0

Elevation of NA-induced enzyme activity. ALS, GST and ACCase activities increased with treatment of NA in maize (Table 2). The greatest increase occurred with ACCase, while the least with ALS. The increases resulted from NA-induced enzyme production. However, elevation of any of the enzyme activities by NA did not exactly correspond to the safening factors. This indicated that effect of NA on the enzyme activation or enzyme induction process had no simple correlation with the protective action.

Table 2. Effect of NA on elevation of enzyme activity in maize

Enzyme	Activity (uM/min/mg protein)		
	Without NA (A)	With NA (B)	B/A
ALS	6.9	9.1	1.3
GST	0.9	1.6	1.8
ACCase	0.025	0.079	3.2

Effect of herbicides on NA-induced enzyme activity. ALS activity decreased linearly with logarithmic increase in bensulfuron concentration starting from 10^{-9}M, while the same effect occurred with imazaquin at 10^{-6}M (Fig. 1). A similar trend was found in NA-induced ALS activity. With both herbicides tested, however, there was difference in inhibition of ALS activity between ALS's obtained from NA-treated and NA-untreated maize. The inhibition difference decreased with increase in herbicide concentration. This difference is due probably either to NA-induced altered ALS forms which are less sensitive to the herbicide inhibition or to *de novo* synthesis of ALS caused by NA, or both.

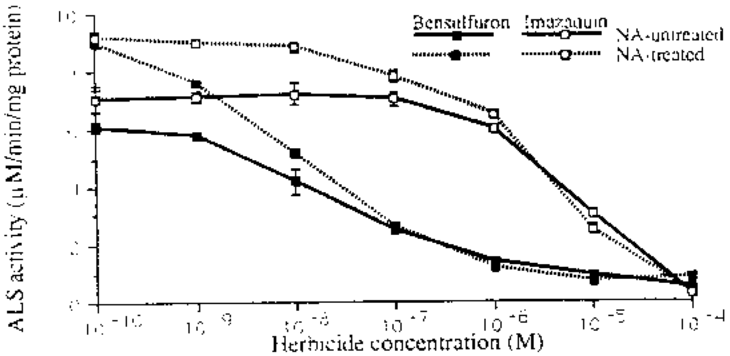

Figure 1. Effect of bensulfuron and imazaquin on NA-induced ALS activity of maize.

Effect of bensulfuron and imazaquin on ACCase activity varied with the source of the enzyme preparation (Fig. 2). Activity of ACCase obtained from NA-untreated maize was not affected by concentration of the two herbicides up to 10^{-5}M. On the other hand, a slight increase in activity of ACCase obtained from NA-treated maize occurred by bensulfuron concentration between 10^{-8} and 10^{-5}M, while there was no significant difference in ACCase activity with imazaquin at the same concentration range. Increase in ACCase activity by bensulfuron might be result of activation of NA-induced ACCase. However, the different response between the herbicide groups was possibly attributed to different sensitivity of the enzyme to the herbicides.

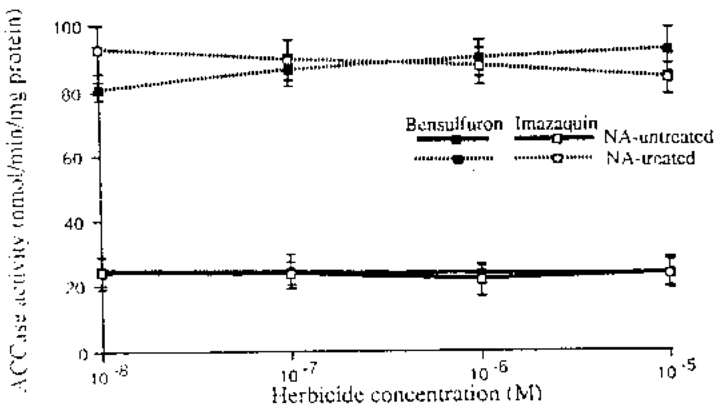

Figure 2. Effect of bensulfuron and imazaquin on NA-induced ACCase activity of maize.

The results presented in this paper demonstrate that NA provided a significant protective action against injury of sulfonylurea and imidazolinone herbicides to maize. The degree of the safening effect, however, varied with the herbicide classes. Safening factors on sulfonylureas were two-fold or greater than those on imidazolinones. This difference may be due either to differential sensitivity of maize to the herbicide classes or to different specificity of NA-herbicide combinations.

In the safening mode of action of NA, NA-induced GST activity may not play an important role. Although NA increased GST activity by about 80%, the NA-induced GST would not act in the detoxication of the herbicides through glutathione conjugation. Frear *et al.* (5) found that NA increased 40-60% GST activity in maize, whereas chlorsulfuron did not alter glutathione content and GST activity. On the other hand, about 30% increase in extractable ALS was also caused by NA. However, the increase appears minor in comparison to the degree of the safening. This fact suggests that competitive antagonistic action of the two herbicide classes and NA on ALS may be excluded in elucidating the potential safening mechanism of action of NA.

The greatest increase in NA-induced enzyme activity studied occurred with ACCase. ACCase catalyzes the first committed step in fatty acid biosynthesis (6) and has been identified as the target site involved in the phytotoxic action of two classes of graminaceous herbicides, the aryloxy-phenoxypropionate and the cyclohexanedione (3). Although increase in ACCase activity by NA is not of sufficient magnitude to account for the safening activity of NA on maize, involvement of ACCase activity in protective action of NA against injury of sulfonylurea and imidazolinone herbicides in maize is rather of interest. This enzyme is not a target site for either sulfonylurea and imidazolinone herbicides or NA. According to the finding of Yenne and Hatzios (12), activity of ACCase extracted from oxime ether safener-treated sorghum, *Sorghum bicolor*, did not differ from that extracted from untreated sorghum. Therefore, it is more likely that NA-induced ACCase may be consequence of NA-maize specificity.

Based on the results obtained, it is reasonable to hypothesize that safening mode of action of NA results from multilevel interaction of enzymes responsible for crop-herbicide-safener combination. Any of the NA-induced enzymes alone could not provide sufficient increase in the enzyme activity to explain the degree of the safening effect of NA. Activities of NA-induced ALS, GST, and ACCase might be required at the same time to exert the protective action of NA against injury of sulfonylurea and imidazolinone herbicides in maize.

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TEBUTHIURON CONTROLS BRIGALOW AND GIDGEE REGROWTH IN QUEENSLAND

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Summary. Woody Acacia regrowth must be controlled if animal productivity is to be maintained on large areas of once productive pastures in Queensland. In 1989 tebuthiuron was aerially applied to brigalow, *Acacia harpophylla*, in central Queensland. 36 months after treatment an obvious dose response indicated that 2.0 kg/ha tebuthiuron resulted in greater than 80% control of brigalow on light clay soils. Regrowth on soils of high clay content (greater than 45%) required a rate of 2.5 kg/ha to achieve similar efficacy. Grass response in treated areas was 4-5 times greater than that of the untreated.

In the more arid conditions of western Queensland aerial application of 1.2 kg/ha tebuthiuron resulted in greater than 80% control of Gidgee, *Acacia cambagei*, regrowth. On previously denuded areas *Astrebla sp.* had re-established 36 months after treatment.

Control of these high density regrowth species, and the resultant increase in pasture yields have improved the sustainability of the grazing industry in Queensland.

INTRODUCTION

Since the mid-1980's in Australia technology has been available to aerially apply pelleted herbicides for broadacre woody weed control. Tebuthiuron is applied to the soil in a clay pellet containing 200 g active ingredient/kg and is moved into the plants root zone by rainfall.

The herbicide inhibits photosynthesis in susceptible plants such as brigalow, *Acacia harpophylla*, and gidgee, *A. cambagei*. Visual effects of soil active herbicides are very slow with repeated defoliation and regrowth occurring. Control ratings may not be conclusive under three years.

The flora, land use and soil types of the brigalow belt have been described by many authors (6, 7, 8, 1, 5). Brigalow regrowth is prolific on soils which range in clay content, pH and gilgai development. In any given paddock there is often a mosaic of light and heavy soil types, ranging from sandy texture contrast soils to cracking clays.

Past clearing strategies have resulted in regrowth of brigalow and other woody weeds with the subsequent adverse affects on pasture productivity. The emphasis today on developing brigalow lands, covering an area of approximately 6 million hectares in Queensland, lies totally with regrowth control and the maintenance of productive pastures. Anderson *et al.* (1984) considered regrowth required immediate control in at least 50% of localities to prevent further pasture deterioration.

Growing as the dominant vegetation unit, gidgee was estimated to cover an area of 3.2 million hectares in central Queensland (13). Various forms of gidgee regrowth and seedling infestation were identified as being the major contributor to lost grazing potential (3).

A survey of producers in this region estimated that 11% of the area has been denuded/lost to woody weed invasion with the species causing most concern being gidgee (10). The spread or invasion of this plant into previously open downs is considered to be increasing. This problem is now more common than regrowth resulting from previous mechanical treatment.

Land degradation is occurring in central and western Queensland on the existing grazing lands of the beef and sheep pastoral industries (11). Woody weed regrowth and invasion have provided the major impact which is predominantly from these two Acacia species. The increase of woody weeds must be addressed if pastures derived from brigalow or gidgee communities are to maintain animal productivity and improve the sustainability of the pastoral industries.

The studies reported in this paper resulted from the aforementioned perceptions. Experiments were carried out to determine the rate of tebuthiuron as Graslan® pellets, which would be needed to obtain commercially acceptable control of brigalow and gidgee regrowth.

METHODS

Brigalow. A fixed wing aircraft applied Graslan® pellets onto brigalow regrowth at five sites throughout the Fitzroy region of central Queensland during October-November 1989. At 3 sites, Moura, Baralaba and Ogmore regrowth was 2 m to 4 m, Dingo 1 m to 4 m and at McKenzie River was 3 m to 4 m.

Treatments consisted of 100x1000 m unreplicated plots with 5 rates of tebuthiuron ranging from 1.5-3.0 kg/ha. An untreated control was included to compare grass response on treated plots. An assessment of canopy cover was obtained prior to treatment and at each assessment to determine plant reduction.

Populations ranging form 10,000-20,000 stems/ha provided sufficient density to seriously impede mustering. With livestock grazing carried out at normal stocking rates (c. 0.25 beast/ha), at all sites the trial occupied a small percentage of any given paddock.

Soil analyses were performed to determine clay content, pH and organic matter content of each site. Daily rainfall was recorded and assessment of herbicide efficacy through canopy reduction was undertaken at 12 monthly intervals for 3 years.

Gidgee. In July 1989 a solo powerblower was used to apply Graslan® pellets from the ground to gidgee seedlings and regrowth in 40x100 m unreplicated plots at 5 sites in the Longreach district of western Queensland. Rates of tebuthiuron were 0.8, 1.0 and 1.6 kg/ha. In September 1989 a fixed wing aircraft applied 1.2 and 1.5 kg tebuthiuron/ha, to large plots (100x500 m) adjacent to each of the ground applied sites, with an untreated control separating the plots. Soil analyses determined clay content, pH and organic matter content at each site, rainfall records were kept at 4 of the sites, and visual assessment of herbicide efficacy was undertaken at 12 monthly intervals for 3 years.

RESULTS AND DISCUSSION

Brigalow. Tebuthiuron efficacy on brigalow regrowth was evident 36 months after treatment (MAT). A rate of 2.0 kg/ha tebuthiuron gave effective (84.7%) control of brigalow regrowth when results were summarised across sites (Fig. 1). Experience indicates that commercial acceptance of this product requires control to be at least 80-85% of all regrowth.

Figure 1. Efficacy of tebuthiuron on brigalow regrowth at five sites in central Queensland

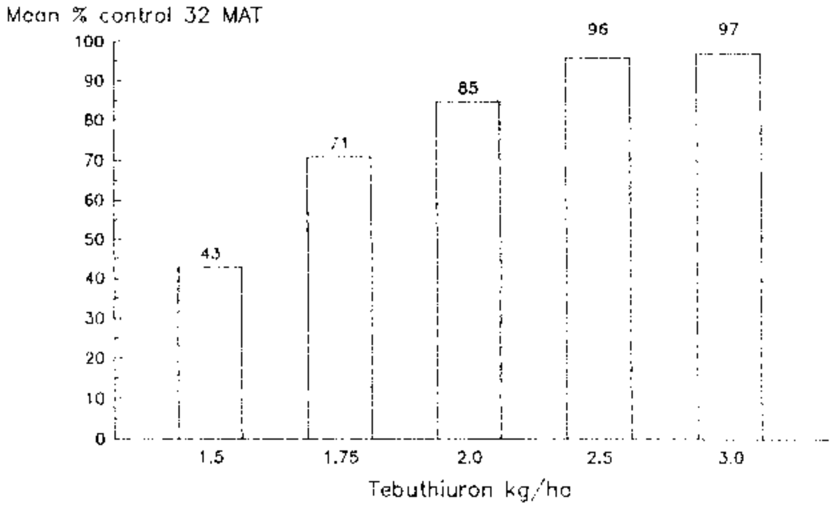
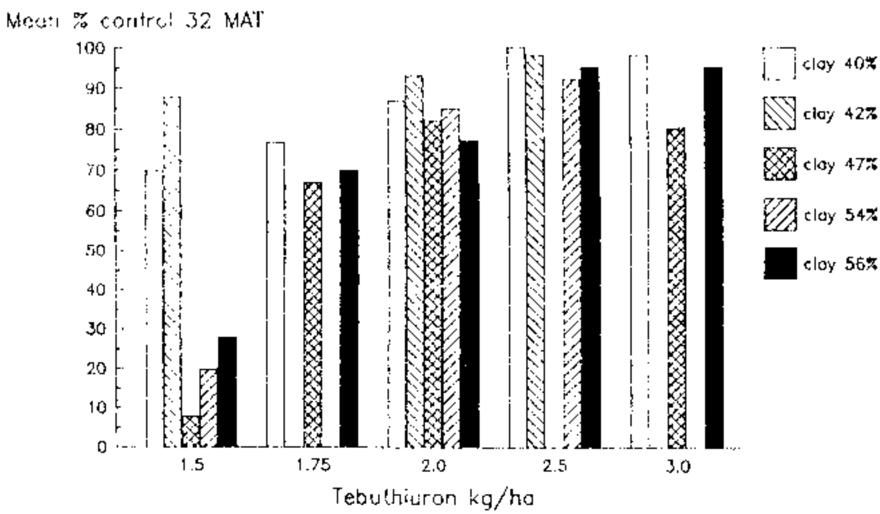


Figure 2. Tebuthiuron rate response by soil type on brigalow regrowth



The activity of the herbicide is sensitive to soil type, as reduced phytotoxicity was noted where soils are acidic and higher in clay content. On the lighter soil types (2 sites at 40% clay), the availability of tebuthiuron to the plant is evident by a 79% kill at 1.5 kg/ha. Regrowth on the acidic heavy clay soils (2 sites at 55% clay content and pH 5.3) required 2.5 kg/ha tebuthiuron to achieve greater than 85% control (Fig. 2).

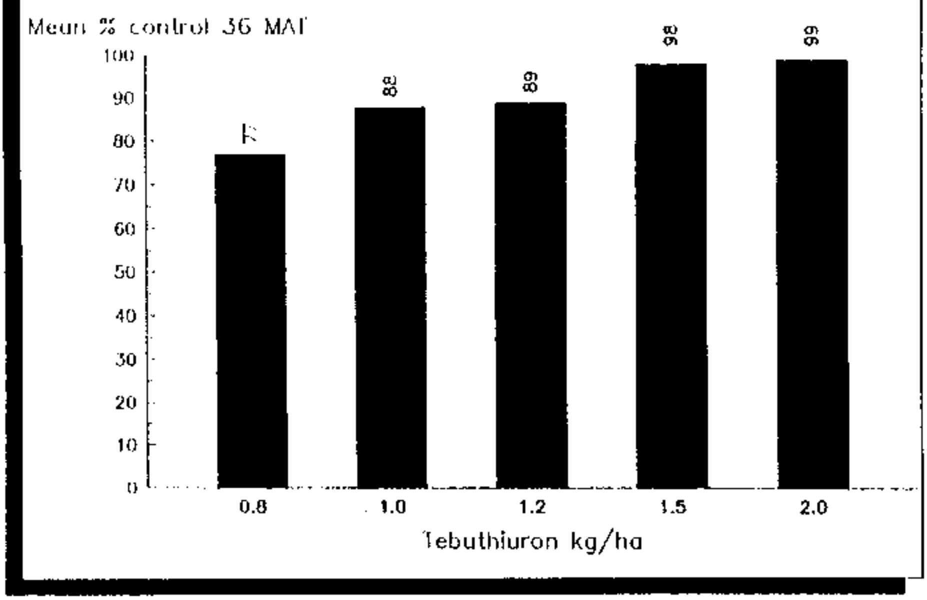
These results indicate that edaphic factors greatly influence the phytotoxicity of tebuthiuron to woody regrowth as reported previously outside Australia (4, 12).

Grass response occurred during the first defoliation cycle and continued to increase reaching 4 to 5 times the control plot at individual sites 30 MAT. Total dry matter yield of buffel grass, *Cenchrus ciliaris*, pastures has been measured at 6450 kg/ha after regrowth was controlled with 2.0 kg tebuthiuron/ha (9).

Although all sites recorded well below average rainfall throughout the trial period, these studies demonstrated the dose response obtained with tebuthiuron in controlling brigalow regrowth.

Gidgee. This Acacia species was highly susceptible to tebuthiuron regardless of application method. At 1.0-1.2 kg/ha greater than 85% control of gidgee regrowth was obtained 36 MAT. A dose response of gidgee to tebuthiuron is evident when the data from 5 sites in western Queensland are summarised (Fig. 3). The edaphic factors were extremely uniform with no variation in tebuthiuron efficacy to gidgee across sites. Clay content was 40-42%, being of neutral-alkaline pH (7.2-8.0) with low organic matter (0.7-1.0%) and indicates that gidgee is adapted to a narrow range of soils in this region.

Figure 3. Control of gidgee with tebuthiuron at five western Queensland sites



Excellent seasonal conditions occurred for a soil applied herbicide to be activated, as summer rainfall during the first two years of the trial was equal to or greater than Longreach's long term average of 320 mm. Winter rainfall was 3.5 times the long term mean (120 mm) during the first year after application, but then fell below this value in the last two seasons.

Death of many annual broadleaf species of forbs and herbs was evident at the lowest rate of tebuthiuron applied. This is not desirable as they provide a valuable protein source for sheep and cattle. However recolonisation of mitchell grass, *Astrebla spp.*, which was not damaged with the highest rate of tebuthiuron, occurred at the base of most dead gidgee stems 36 mAT.

It is evident that regrowth and invasion of brigalow or gidgee has adversely affected pasture productivity, with subsequent losses in animal production, in a large area of Queensland. Results from these field experiments using tebuthiuron to obtain effective control of 85% of these high density regrowth and invasive species has demonstrated that woody weeds can be managed in these established grazing lands. The resultant grass response following the reduction of competition for soil water and nutrients indicates how Graslan® can aid in the long term sustainability of pastoral industries based on brigalow and gidgee lands in Queensland.

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CONTROL OF CHINESE SHRUB WITH TRICLOPYR/PICLORAM AND GLYPHOSATE BY HANDGUN APPLICATION

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Summary. Chinese shrub, *Cassinia arcuata* is a hardy native perennial evergreen that has spread widely in New South Wales and become a weed in many situations. Handgun foliage spray trials were conducted at Orange and Yass during 1989 and 1990 to determine the best herbicides and the most suitable time to control Chinese shrub. The two most cost-effective treatments were 1.5 g ae triclopyr + 0.5 g ae picloram/L of water + 0.2% v/v 600 g/L non ionic surfactant and 4.68 g ai/L glyphosate + 0.2% v/v 600g/L non ionic surfactant. Autumn application was superior to early summer.

INTRODUCTION

Chinese shrub (biddy bush or sifton bush) grows mostly on infertile, acid, stony soils but has recently spread to more fertile soils where pasture competition has been weakened. A heavy infestation of Chinese shrub can reduce stock carrying capacity by 90%. In 1977, 93,000 ha in NSW was infested with the weed, over 23 shires (1) and by 1988 this had grown to 616,000 ha over 31 shires, the heaviest infestations being in the central and southern tablelands and slopes. Control measure have included chipping, pulling, brush cutting, burning, slashing and herbicide application.

Experiments were established in co-operation with the Department of Agriculture at Orange in central NSW and Yass in Southern NSW to evaluate high volume (handgun) post-emergence herbicide spraying in non-arable situations.

METHODS

Treatments were in randomised complete blocks with 3 replications. Plot size was 20x4 m at Orange and 10x4 m at Yass. High volume application was by handgun with D6 orifice at a pressure of 550 kPa. Both sites had two application timings, the first was in early summer 1989 and the second was in autumn 1990. At Orange both timings included triclopyr (butoxyethyl ester), fluroxypyr (methyl heptyl ester), 2,4-D amine + picloram, glyphosate and hexazinone and tebuthiuron pellets were included in the autumn treatment. Plants were 0.1-2.0 m high and pre-flowering in early summer and 1.5-2.0 m high and flowering in autumn. Plant density was 2.5-3.5 per 1x1 m.

Pasture competition is important in the control program. Four kg/ha of Woogenellup subterranean clover was hand broadcast with 125 kg/ha Mo superphosate onto the bottom 10 m of each plot 5 months after application (maa).

At Yass Chinese shrub was regrowth after slashing and in early summer was 0.5-1.5 m high (pre-flowering), 31 plants per 1x1 m and in autumn was 0.5-2.0 m (post-bloom), 10 plants per 1x1 m.

Herbicides varied with the time of treatment and pasture was not sown. In early summer herbicides included triclopyr + picloram, clopyralid (amine), glyphosate, hexazinone and metsulfuron-methyl and in autumn included triclopyr, triclopyr + picloram, clopyralid, fluroxypyr, tebuthiuron, glyphosate and hexazinone. Results were based on visual ratings and plant counts at Orange and visual ratings only at Yass. Results were analysed in Statgraphics by anova and mean separation was by Tukey h.s.d.

RESULTS AND DISCUSSION

Orange, early summer application. Most of the treatments gave promising brownout 2 months after application (maa) but vigorous regrowth occurred. At 11 maa 4.2 g/L fluroxypyr (66% control), 0.83 g/L hexazinone (51%) and 0.5 g picloram + 1.5 g triclopyr/L (Grazon* DS) + 0.2% v/v non-ionic surfactant (Agral# 600) with 40% control were the only 3 treatments out of 17 which gave more than 25% control.

Subterranean clover counts 1.5 months after seeding ranged from 15-69 per 1x1 m but there was no significant differences for clover establishment with herbicides compared to untreated which was 40 per 1x1 m, based on 95% Tukey h.s.d.

Orange, autumn application. This timing provided better results. The two most commercially viable treatments at 6 and 12 maa were 0.5 g picloram + 1. 5 g triclopyr/L alone (91% control), or + 0.2% v/v Agral 600 (94%) and 4.68 g glyphosate/L + 0.2% v/v Agral 600 (92%). Picloram 0.7 g + 2.1 g triclopyr/L gave 97% control of Chinese shrub. There was no advantage in adding oil/wetter or organo-silicone surfactant to glyphosate or oil/wetter to Grazon DS.

Sub-clover counts 2 months after seeding ranged from 15-45 per 1x1 m and the untreated was 19 per 1x1 m. There was no significant difference in counts between treatments (95% Tukey h.s.d.). Clover flowered in early October 1990 in the untreated, glyphosate, fluroxypyr and triclopyr treatments. Clover did not flower in triclopyr + picloram or hexazinone plots.

There was no significant re-invasion of plots by Chinese shrub seedlings with triclopyr + picloram and hexazinone but there was in glyphosate plots.

Yass, early summer application. At 11 maa control with 0.42 g/L and 0.83 g/L hexazinone + oil 0.5% v/v was 98-100%, 0.5g picloram + 1.5g triclopyr/L + Agral 600 0.2% v/v gave 94% control and 3.6 g/L glyphosate + 0.2% v/v organo-silicone surfactant (Pulse®) gave 90% control of Chinese shrub. These treatments were significantly better than others (95% Tukey h.s.d.). The above rate of glyphosate with 0.2% v/v Agral 600 gave 81% control. Metsulfuron-methyl gave no control of Chinese shrub.

Results at Yass for this timing were better than at Orange, perhaps due to the older and more variable Chinese shrub population at Orange.

Yass, autumn application. All treatments gave excellent control of Chinese shrub with 0.5 g/L clopyralid + 0.5% v/v oil showing the lowest control at 87%, 13 maa. Glyphosate 3.6 g/L + adjuvants at 0.2% v/v gave quick brownout and better kill with this spray timing. Organo-silicone and oil/wetter adjuvants improved brownout but not the level of control of Chinese shrub which was 99% 13 maa.

Grazon DS + 0.2% v/v Agral 600 was slower than glyphosate at 1 and 3 maa but gave similar control (99%) at 6 and 13 maa with both 0.35 g picloram + 1.05 g triclopyr/L and 0.5g picloram + 1.5 g triclopyr/L.

Hexazinone at 0.42 g and 0.83 g/L + oil/wetter gave almost complete brownout 6 maa and 100% control 13 maa. Clopyralid 0.5 g and 1.0 g/L + oil gave 85% and 99% control respectively and 2.4 g/L triclopyr + 0.2% v/v Agral 600 gave 92% control of Chinese shrub 13 maa.

Autumn results at Yass were better than those obtained at Orange, perhaps because the Chinese shrub at Yass was even height (0.5-2 m) regrowth and less mature than at Orange. A summary of results with picloram/triclopyr (Grazon DS) and glyphosate) Roundup with adjuvants is shown in Table 1.

Table 1. The effect of picloram/triclopyr and glyphosate on Chinese shrub at Orange and Yass.

Herbicide	g/L	Adjuvant % v/v	% Control			
			Orange		Yass	
			Summer 11 maa	Autumn 12 maa	Summer 11 maa	Autumn 13 maa
picloram/triclopyr	0.35 + 1.05	0	5	67	-	-
"	"	0.2[a]	-	-	68	99
"	0.50 + 1.50	0.[a]	24	91	-	-
"	"	0.2[a]	40	94	94	99
"	"	2.0[b]	33	94	-	-
"	"	0	40	97	-	-
"	0.70 + 2.10	0.2[a]	-	-	70	99
glyphosate	3.60	0.5[c]	-	-	70	99
"	"	0.2[d]	-	-	90	99
"	"	0.2[d]	12	92	82	98
"	4.68	2.0[b]	18	94	-	-
"	"	0.2[d]	21	76	-	-
clopyralid	0.50	0	-	-	8	87
"	1.0	0	-	-	33	99
fluroxypyr	2.1	0	18	56	-	-
"	4.2	0	66	89	-	-
hexazinone	0.42	0	6	6	98	96
"	0.83	0	51	14	100	100

[a] non-ionic surfactant (Agral 600).
[b] oil/surfactant (D-C-Trate).
[c] oil (Caltex).
[d] organo-silicone surfactant (Pulse).
-, not used.

Despite good results with both times of spray at Yass and similar results in a separate experiment on 0.25-1 m high Chinese shrub at Mullion Creek where the best treatments (Grazon DS, glyphosate and hexazinone, all with adjuvants) gave similar results with December 1989 and

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March 1990 handgun spraying (B. Milne, pers. comm., 1990), general use recommendations for Grazon DS will promote autumn application for handgun spraying of Chinese shrub.

The two most cost-effective herbicides for Chinese shrub control from this series of trials were 0.5 g picloram + 1.5 g triclopyr/L (Grazon DS 1 L/100L) + 0.2% v/v Agral 600. Glyphosate is the most compatible treatment if legume pasture sowing is to occur soon after spraying. Glyphosate killed competitive ground cover and a high level of re-invasion of Chinese shrub seedlings occurred.

Grazon DS retards the growth of legume pasture and prevents re-establishment for a period after spraying but grasses are left to compete with invading weed seedlings, significantly reducing the population of Chinese shrub. Registration of Grazon DS was obtained in 1992.

Mechanical methods referred to in the introduction are also important in controlling Chinese shrub along with management of livestock. Brush-cutting as close to the soil surface as possible and tearing plant stems rather than evenly cutting and slashing plants more than 2 years old and more than 1 m high have been effective, especially when soil moisture is low however stumps cause costly punctures to rubber tyres in the short term (R. Gammie, pers. comm., 1990). Burning is effective on larger plants but there can be seedling invasion and bushfire risk.

ACKNOWLEDGEMENTS

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POND APPLE *(ANNONA GLABRA)* - A NEW AND AGGRESSIVE WEED OF WETLANDS IN TROPICAL QUEENSLAND

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Summary. Pond apple is a small semi-deciduous tropical American tree which is spreading aggressively throughout freshwater and brackish coastal wetlands in tropical Queensland. It is also established along an inland creek in rainforest. Coastal wetlands along both sides of the Timor Sea must also be at risk. Long distance transport of seeds is by ocean currents, and local spread primarily by flood waters. High seedling densities cause severe competition with native species, and the rapid replacement of native vegetation by stands of pond apple. Pond apple is very sensitive to fire. Accessible trees can be controlled by stem injection with triclopyr plus picloram or by glyphosate, and by basal bark spraying with triclopyr plus picloram.

DESCRIPTION

Pond apple (*Annona glabra* L.) is a semi-deciduous tree to 10 m tall. It originated in the swamplands of tropical North, Central and South America (2), and was possibly introduced into Queensland as a wetland rootstock for cultivated species of *Annona*.

Plants are usually only 3-6 m tall and single trunked, but multiple stemmed plants are also common since several seedlings may germinate together and new shoots often arise around the bases of established plants. The softwooded stems have a thin greyish bark with prominent lenticels, and when cut exhibit a 1-2 cm diameter pith surrounded by several indistinct growth rings for each year of its age. The wood and roots float readily whether fresh or dry, but when dead they rot away within a few years if they are exposed to damp conditions.

Several growth flushes occur each year, from terminal and axillary buds. Each flush consists of about eight leaves arranged alternately along the new stems, among which one or occasionally two axillary flower buds normally develop on well lit branches. The leaves are ovate, smooth edged, sharply pointed and a distinctive dull green in colour, with a characteristic scent when crushed.

The single flowers have two small sepals and are enclosed within three large green leathery outer petals and three similar creamy inner petals. The petals scarcely open at anthesis. The flowers have numerous stamens and separate carpels, and pollination is probably by small flying insects. After pollination the petals and stamens are shed, and the carpels fuse together to form a smooth oval to spherical compound fruit 5-8 cm long which changes from green to orange or yellow when ripe. Each fruit contains about a hundred large woody seeds.

At maturity the whole fruit falls from the tree, and both the fruits and individual seeds are capable of floating and remaining viable for long periods in fresh, brackish and sea water. The seeds have an innate dormancy of several months, after which they germinate in masses, grow quickly in height, and rapidly form monospecific stands to the exclusion of other species.

ECOLOGY

Pond apple originated in the freshwater and brackish swamplands of tropical North, Central and South America and coastal West Africa (2), where it behaves as a fresh and brackish water mangrove. It survives root immersion in brackish water every high tide, and also prolonged (but not permanent) shallow flooding with freshwater. Its fruits and seeds appear to be spread mainly by water, but local spread also occurs through ingestion and defecation by larger frugivores such as feral pigs and cassowaries.

Seedlings require moist to wet and well-lit conditions for germination and early growth, which they find on riverbanks, floodplains, marshes and areas previously covered by seasonal grasses, sedges, ferns (eg *Acrostichum* spp.) and tea trees (*Melaleuca* spp.), many of which have traditionally been seasonally burnt to retain them as fire disclimaxes.

Pond apple has become established along a permanent creek through rainforest inland from Cairns, where it occurs only on the moist soils very close to the creek and barely survives due to competition from taller trees. Rapid growth and reproduction occur in areas along the creek where the rainforest has been cleared.

DISTRIBUTION

Pond apple occurs sporadically in coastal and subcoastal Queensland between Ingham and Cooktown. Its greatest concentrations occur in the seasonally inundated floodplains of the Murray River, in the swamplands along Nind's Creek near Innisfail, and in the swamplands along the lower Russell River and its estuary. An unconfirmed collection of pond apple from Temple Bay just south of Cape York suggests that it may extend much further north than confirmed collections suggest.

Long distance transport appears to be by ocean currents; it is the only member of the genus to have spread naturally from Tropical America to the west coast of Tropical Africa. Floods carry fruits and seeds out to sea, where they appear to move with the northwards drift along the Queensland coast. Seedlings then appear along shorelines and in creeks and estuaries. High spring tides and floods then redistribute fruits and seeds throughout infested floodplains.

IMPACT

The dense and rapid growth of pond apple seedlings quickly shades out endemic grasses and sedges, removing the ground fuel component so that after a few years burning is no longer possible. The subsequent dense growth of pond apple also prevents germination of the small seeded tea trees, resulting in a tendency towards monospecific stands of the single exotic species.

Areas potentially at risk from pond apple include the extensive floodplains, estuaries and upper edges of the mangrove swamps of the rivers draining into the Coral Sea on the north-eastern side of Cape York Peninsula, and similar areas of both the Fly and other rivers on the southern side of Papua New Guinea and Irian Jaya and the estuaries and floodplains of the Top End of Northern Australia, including Kakadu National Park. Pond apple may also move southwards along the Queensland coast and inland onto the river systems of the Gulf of Carpentaria.

CONTROL

Pond apple is sensitive to fire at all stages of its growth, and where fire can be used this is the preferred method of control. Where sufficient dry fuel has accumulated in the ground layer a hot fire will kill both seedlings and isolated trees, and probably also any seed lying on the soil surface. Many of the areas invaded by pond apple were traditionally burnt during Aboriginal management, but recent changes in land use coupled with fragmentation and much reduced fire frequency have allowed pond apple to proliferate in them. Chemical or physical control of pond apple will usually allow the regeneration of native and grasses, after which the area could be burnt sufficiently often to prevent significant reestablishment of the pond apple.

Biological control appears to be the best long term strategy for the management of pond apple, since it is both widespread and also firmly established in almost inaccessible areas of high conservation value. Possible problems with this approach are that there are several species in the same and a closely related genus (Rollinia) which are grown commercially and in gardens for their fruits, and that there are about thirty endemic species of Annonaceae in the rainforests of north Queensland.
Pond apples are easily uprooted by mechanical means, but this method is expensive and unsuitable for most of the wetlands and conservation areas which the Plant has invaded.

The plant is readily susceptible to stem injection with glyphosate and with triclopyr plus picloram based herbicides (3); several other herbicides are being tested for its control by stem injection and basal bark (wet stem) application.

DISCUSSION

Pond apple is firmly established in wetlands throughout coastal and subcoastal tropical Queensland, and appears to threaten similar areas (many of high conservation value) around northern Australia and southern Papua New Guinea and Irian Jaya. If left uncontrolled the plant has severely damaging effects on the native vegetation of such areas, most of which are very difficult to access for control.

Pond apple is a potentially severe (category 1 - canopy dominating) (1) environmental weed throughout coastal northern Queensland, and requires coordinated control by a range of legislative, managerial (burning), chemical and possibly biological methods.

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SALVINIA MOLESTA IN KAKADU NATIONAL PARK: BIOLOGICAL CONTROL

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Summary. Releases of the salvinia weevil, *Cyrtobagous salviniae*, in 1984/85 to control salvinia, *Salvinia molesta*, in Kakadu National Park resulted in establishment and spread but not satisfactory control. A preliminary study suggested that lack of control may have been due to high temperatures (9). In 1991 CSIRO began a consultancy for ANPWS to monitor the environment, the weevil and the weed to determine why biological control was not successful. The results so far suggest that weevil abundance declined after the weed was severely damaged and that temperature was not a major limiting factor. Successful biological control occurred in some billabongs while in others, similarly heavily damaged mats failed to sink because they were tightly packed and held together by other vegetation.

INTRODUCTION

Kakadu National Park, located in the Northern Territory of Australia, approximately 300 km east of Darwin, is dominated by two major river systems, the South Alligator River and the East Alligator River. The floating weed, salvinia, was first found in the Park in 1983. Manual removal and chemical control of salvinia was not successful and it quickly spread to cover all major billabongs on Magela Creek, a tributary of the East Alligator River (9).

Releases of the salvinia weevil were made on Magela Creek in 1984 and 1985 (9). The weevil established, spread and severely damaged the weed in the years following its release (C. Wilson and A. Skeat pers. comm., 1990). However, during the period 1987 to 1989 there was little flushing of Magela Creek during the annual wet season, activity by the weevil apparently did not prevent growth of the weed and salvinia spread to cover much of the surface of the billabongs. Concern for the wetlands increased and steps were taken to reduce the chances of the weed spreading by restricting access to infested areas and inspecting vehicles after they crossed infested streams. Unfortunately, salvinia was found in Nourlangie Creek, a tributary of the South Alligator River, in 1990 where it has since spread to infest a number of billabongs and associated swamplands.

Between 1986 and 1989 Skeat (9) determined a significant negative correlation between adult weevil numbers and temperature. He concluded that the apparent relationship between high water temperature and low weevil populations required further study. In July 1991 ANPWS contracted CSIRO Division of Entomology, to determine the factors that were preventing satisfactory control of this weed.

METHODS

Five study sites were selected in billabongs on Magela Creek where environmental parameters, plant growth and weevil activity were recorded. A floating wire mesh pontoon was located amongst salvinia at each site. A 2x2 m floating quadrat was placed within each pontoon and observations were made within the quadrat. The pontoons provided protection from crocodiles and support for the observer and equipment including temperature sensors and data loggers.

Two hundred adult weevils were released onto salvinia in the floating quadrats in each pontoon. One hundred terminal ramets of salvinia were inspected each week and the numbers of terminal buds damaged by the weevil and the numbers of adults observed were recorded. Populations of the weevils and the damage they caused were similarly monitored at locations away from the pontoons. These populations originated from the initial releases made in 1984/85.

Relative growth rates (RGR) for salvinia were measured at Ja Ja and Jabiluka Billabong sites in uncrowded conditions. Thirty salvinia plants were collected from the billabong. Fifteen were dried and weighed and the number of ramets per plant recorded. The other fifteen were placed into a 1x1m floating quadrat. After two weeks, the fifteen plants from the quadrat were dried, weighed and the number of new ramets recorded. This was repeated every two weeks at both sites and the RGRs for dry weight and for numbers of ramets were calculated (3).

Daily maxima and minima and hourly temperatures were recorded at each site by sensors located as follows. In a mini-screen 1.5 m above water level, in shade 10 cm and 2 cm above salvinia, in water 2 cm and 10 cm below the surface and in a salvinia plant. Daily rainfall was recorded at each site.

Samples comprising 15 plants of salvinia were collected each week, dried, ground and analysed for concentrations of nitrogen (N), phosphorus (P) and potassium (K).

RESULTS AND DISCUSSION

Temperature. Temperature relations of the weevil have been studied in some detail (2, 8) and the optimum range for development is approximately 25 to 36°C. However, little is known about the effect of higher temperatures on this weevil. The effects of temperature on the weed are well known for normal field temperatures, the optimum for growth being 30°C (6). Buds exposed to constant temperatures above 43°C for more than 2 or 3 hours died (10).

Maximum temperatures at Jabiru are 3°C higher than Darwin during September, October and November: the average maxima for Jabiru were 35.7°C, 37.5°C and 36.5°C, respectively. Climate matching using CLIMEX found no other area in the world known to have salvinia with similar climatic pattern and high summer temperatures except Oenpelli which is within 100 km of Jabiru and had a high temperature match of 96%. The high temperature match with Darwin was 71%.

Temperature variation between sites. Temperatures for similarly located sensors varied between the five sites on the Magela by +-1.5°C for maxima and +-1.25°C for minima but the differences were not systematic. Consequently, further discussion here will include two sites only.

Salvinia temperatures. Daily minimum temperatures were within the range known to be suitable for growth of salvinia and development of the weevil. Averages did not exceed 35°C and were mostly between 28°C and 32°C, within the optimal range for the weevil. The maximum temperatures exceeded 45°C on a number of occasions between December 1991 and March 1992 but rarely during the same period in the following year. Maximum temperature exceeded 40°C almost daily during the same periods. On very hot days hourly averages can exceed 40°C for up to five hours.

Water temperatures. The adult weevils are mobile and can seek cooler or warmer situations while immature stages are less mobile being inside the stem as larvae or under water, in cocoons as pupae. Consequently we consider that temperatures measured just below salvinia provide a more realistic indication of temperatures experienced by all stages of the weevil. The daily minima are higher and the maxima lower in water than in salvinia. The absolute maximum temperatures in water rarely exceeded 40°C, occasionally exceeded 38°C and were mostly within the range suitable for weevil activity. An inspection of hourly water temperatures for hottest days indicated that the maxima were considerably lower, under 38°C, and the period of time when temperatures may adversely affect the weevil was much shorter, than in salvinia. On most summer and all winter days, temperatures remained within the range for normal activity by the insect.

Rainfall. Most rain fell as storms that effected some parts of the floodplain but not others. Rainfall in the Magela Creek catchment area, not necessarily in the study area, was important as run-off and flooding, and had significant impacts on the Magela system.

In the 1991/92 wet season, rainfall was such that the billabongs filled slowly and the flood water moved slowly down the system. Flooding peaked on the 30 January 1992 at Ja Ja Billabong and three weeks later, 20 February 1992, at Jabiluka Billabong, a distance of 6 km. As a result little flushing of the billabongs occurred. In the 1992/93 wet season rain fell in a much shorter period, 25 to 26 January 1993, causing floods that swept down the system within days. Salvinia mats were flushed onto the floodplain.

Nutrients in salvinia tissue. The main factor influencing growth of the weed besides temperature was the availability of nutrients (6). Level of nitrogen in host plant tissue also influenced the life cycle and population dynamics of the weevil (1,7,8) and the rate and amount of damage the weevil caused to the weed (4, 5).

Nitrogen concentration in salvinia tissue was relatively high in billabongs in Kakadu, the average for all sites was 1.24%. The relatively high biotic productivity in these tropical billabongs probably contributed to high nutrient levels in water and to deposition of nutrient rich sediments. However, concentrations were lowest in the upstream billabongs suggesting that run-off in the upper Magela Creek carried lower nutrients than run-off from the floodplains that surrounded the downstream billabongs. In Ja Ja and Jabiluka Billabongs, located on the floodplain, nitrogen in salvinia peaked sharply when the annual summer floods occurred. Run-off and flow that stirred sediments made nutrients available to the weed. As biomass of salvinia increased on these billabongs, nutrients became relatively scarce and N in tissue declined towards the end of the dry season. The levels of N, P and K in plant tissue were within ranges observed elsewhere in the world where biological control was successful and did not restrict weevil populations in the billabongs.

Relative growth rates (RGR) of salvinia. The availability of nutrients was the major factor that influenced growth of salvinia in the billabongs. RGR was highest, in Ja Ja and Jabiluka Billabongs following flooding when N in tissue was highest, and lowest during the dry season, when there was no flow and nutrients were scarce. The flood peak in 1991/92 took three weeks to move between these two billabongs, and N and RGR peaked at Jabiluka about three weeks later than at Ja Ja. High temperatures experienced by salvinia during summer did not appear to restrict growth.

RGR was similar to the ranges observed elsewhere in the world for salvinia and allowed the weed to double its weight, measured as dry weight, in less than 6 days when growth was fastest, and under 19 days when growth was slowest.

Weevil abundance, plant damage and biological control. Adult weevil numbers and buds damaged increased during August, September and early October and declined thereafter. At Ja Ja Billabong site, for example, the first field generation of adults peaked in September 1991 with 16 adults per 100 buds when 60% of buds were damaged. This was followed by the emergence of second (in late October) and third (in December) field generations, which were smaller than the first and caused less damage. This trend occurred at each study site, including sites where the field populations were being monitored, and always before the hottest period of the year. Though temperature appears not to have been the primary cause, the reasons for the decline are not clear.

The weevil damaged the weed to such an extent, that in some billabongs during 1992, successful control of the weed was achieved in under eight months. The lack of control in other billabongs was not due to low damage by the weevil, but to physical and biological factors preventing the damaged mats from sinking. The heavily damaged mats were so tightly packed or bound together by other vegetation that they were prevented from sinking. However, in February 1993, annual floods removed the remaining mats of salvinia.

Populations of weevils and buds damaged remained low and constant on salvinia growing in a floating grassmat. The salvinia always appeared healthy and green in this situation. This phenomenon has been observed in Botswana (I. W. Forno, pers. comm., 1993) and in PNG (M. H. Julien, unpub. obs., 1993). In both countries biological control has been successful for some years. On Magela Creek billabongs, grassmats remained intact after heavily damaged mats had sunk or been removed by floods. It is likely that grassmats provide a reservoir of salvinia for the next season's growth and support low populations of the weevil that invade the next season's new growth.

When annual floods failed to flush salvinia mats from billabongs enormous build up of biomass followed. This was the case during the period 1987 to 1989. It appears that when damaged mats were not flushed out, regrowth occurred from dormant buds within those mats. The following season's growth of salvinia and other vegetation added to the already high biomass and contributed to a thickening mat of mixed vegetation. Such mats provide habitats that are much less suitable to the weevil. They are less likely to sink, require larger floods to flush them out of the billabongs and are more difficult to control.

We are planning to test the use of herbicides, integrated with biological control, to reduce surface covered by salvinia. Judicious use of herbicides during the early dry season may prevent billabongs from becoming covered with salvinia without destroying weevil populations. Once weevil populations develop, biological control should take over. In billabongs where salvinia is heavily damaged by the weevil, but mats are bound together by other vegetation, herbicides might be used to kill the binding plant species and thus promote sinking. This may help prevent the massive accumulation of biomass that can occur if successive season's growth is permitted to accumulate.

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LUDWIGIA PERUVIANA - DESCRIPTION AND BIOLOGY

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Summary. *Ludwigia peruviana* is an aggressive species introduced from the Americas and invading coastal south-eastern Australia. Its biology and ecology were studied in a series of shallow urban lakes known as the Botany Wetlands and also in glasshouse experiments. The plant produces a profusion of flowers and seeds in summer. Seed production and viability is high; vegetative reproduction from fragments is efficient and the plants thrive in a range of water regimes. Shade, salinity and burying under >2 cm of soil inhibit germination of fresh seed. As the seed ages its germination is less affected by these factors.

INTRODUCTION

The aquatic species *Ludwigia peruviana* (family Onagraceae) has colonised a large part of the Botany Wetlands, an area covering about 45 ha and 11 ponds near Botany Bay, Sydney. The Wetlands drain a densely populated part of Sydney's Eastern Suburbs and the sediments and water are nutrient-enriched. It was first recorded naturalised here in 1970 and recognised as having the potential to become a weed in 1971. The species was cultivated at the Royal Botanic Gardens in 1907. Since 1907 it has been collected from Heathcote (about 40 km south of Sydney), and Gosford (about 80 km north of Sydney). Numerous sightings have been made within 30 km of Sydney.

L. peruviana is a cold-deciduous perennial shrub growing to about 4 m tall, with attractive yellow flowers and hairy lanceolate, mostly alternate, leaves (8,9). Stems are woody, but break easily. The root system is poorly developed and new season's growth is often from fallen stems. The species is native to Central and South America, and considered post-European in the southern United States. It is now naturalised in Asia, Indonesia, India, North America and Australia.

L. peruviana has seldom been reported as a weedy species. In 1977 it was recorded from Malesia without comment and 10 years later (5,6) it was twice recorded as a minor weed in Indonesia. In Florida, USA, both *L. peruviana* and *L. octovalvis* are regarded as invaders of disturbed wet habitats (10); however it is not as aggressive and dominant in central Florida as it is in Sydney, Australia. *L. peruviana* is a declared noxious plant in the Municipality of Botany, Sydney.

Concern over the weed potential of *L. peruviana* has increased in recent years by its behaviour in the Botany Wetlands and the comparatively recent spread of the species from this locality. In areas where it has been established longest, unispecific stands have been formed, native waterplants have been crowded out and bird populations diminished.

Several aspects of the biology of germination and establishment of *L. peruviana* were investigated to aid formulation and implementation of management strategies.

METHODS

Three transects were set up within 2 ponds. The transects were at rightangles to the shore and ran through dense unispecific *L. peruviana* stands. Transects T1 and T2 located in pond 1, were 24 and 20 m long respectively. Transect T3 was 20 m long and in permanent water, whereas in T1 and T2 *L. peruviana* was growing in saturated sand located in an intermittently flooded area. These transects were used as the basis for all sampling, including obtaining seed and soil for seed bank studies, and to determine biomass, standing seed bank, flowering and fruiting phenology, and seed production. Methods as previously described are detailed in (1).

Glasshouse experiments were conducted at the Royal Botanic Gardens Sydney and by the Science Club at St George Girls' High School. Experiments at St George Girls' High School investigated the germination responses of *L. peruviana* to different levels of shading, temperature, salinity, emergence from different depths of soil, and seed longevity. The methods used are documented in (1,4).

Experiments at the Royal Botanic Gardens concentrated on an estimate of the soil seed bank, vegetative growth from different-sized stem fragments, the effect of variable water levels on new shoot growth, buoyancy of seeds, the effect of water turbulence on germination and buoyancy, and theoretical viability using tetrazolium dye. Methods are detailed in (1).

RESULTS AND DISCUSSION

The standing crop consisted of dense erect stems with many side branches. Biomass estimates of above-ground dry weight were about 1500 g/m^2. Stems contributed 83% of the total above ground biomass, and leaves most of the remaining 17%. Regrowth on cleared quadrats was about 74 g/m^2 /week. The number of seeds remaining over winter in old fruits on these stems averaged about 300 000/m^2. The stands were unispecific, dense and, during peak growing season, intercepted 93% of incident light measured at midday. Under the dry conditions of the 1990/91 growing season, most flowering occurred in autumn, Though some flowers were present most of the time, flowers lasted only a day and some petals had often fallen by late afternoon.

Germination and establishment. The minute seeds are hydrophobic, they germinate while afloat and remain afloat indefinitely in still water. However in turbulent water the seeds sink. They can germinate underwater but the seedlings eventually float to the surface. The floating seeds/seedlings allow *L. peruviana* to form floating islands and also line the shores of water bodies.

Under laboratory conditions 80% of seeds germinated. Viability of seeds collected was assessed at 99% using tetrazolium dye. The differences between the germination and tetrazolium dye tests could be explained by at least two possibilities: (i) the difference reflects the problem in attempting to accurately estimate viability using tetrazolium dye (2), or (ii) the difference represents a store of dormant seeds entering the seed bank. The second option is being tested in a series of continuing experiments and early results indicate that this is the most likely explanation. Dormant seeds in the seed bank will greatly affect management options.

Optimum light levels were between 60-75% of incident light with fresh seed, but the effect of shading became less obvious as the seed aged in storage. With old seed only, the highest level of shading inhibited germination.

Increasing salinity decreased germination in fresh seed but in stored seed this result was also ameliorated, and levels of about 0.2 M NaCl were needed to depress germination.

Viability has increased with storage though no figures yet approach the positive tests with tetrazolium dye. There is some indication that dormant seeds may be starting to germinate but not all dormancy appears to be broken after one year. Potential longevity is another factor critical to the management options and studies on this will be continuing.

Seed bank trials are still producing seedlings two years after beginning seed bank studies, though the germination rate is dropping. So far the results are consistent with the germination test percentages and the tetrazolium percentages if the difference is due to hard seeds or dormancy. If this is the case then only low germination would be predicted for the next wetting cycle.

There is some discrepancy between results from germination trials and seed bank studies. In wet soil it is obvious that germination is more extended than under experimental conditions. The continued emergence over several months of seeds in the seedbank trials presumably represents the gradual break down of dormancy of the hard-seed component of the seed bank. The maintained emergence of seedlings at a much slower rate after two wetting and drying cycles can, so far, also be explained by this. The seedbank trials are continuing and the results of these, and the result of longevity in storage, will be critical for the long-term management options.

Soil depth experiments show that very few seeds emerge from a soil cover of >10 mm. Washing out the seeds showed that most non-emerged seeds had germinated and died before reaching the surface. The 1-2% emerging from 20 mm of soil still represents a potential 650 seedlings/m^2.

There was no significant effect of temperature on germination. While there seemed to be a non-significant trend for lower temperatures to depress germination in fresh seed, this disappeared when stored seed was tested. This contradicts field observations where germination is virtually non-existent over winter but the absolute minimum temperatures may be more significant than the mean figures used for the analyses

<u>Vegetative fragments</u>. *L. peruviana* can establish from stem fragments. There is a relationship between shoot frequency of vegetative growth and stem fragment diameter and length. The larger fragments (both diameter and length), always had a higher percentage of shoots. This could reflect the food reserves available to the growing shoots.

Water depths of 10-20 cm had little detrimental effects on the establishment of new plants from new shoots in summer. The strongest of the new shoots were able to survive flooding and grow to become emergent shoots. The percentage of shoots able to reach the water surface was inversely proportional to the water depth. Food reserves in the plant may also have an effect on survival. For flooding to be effective in the control of *L. peruviana*, it may be necessary to submerge the plants by more than 1 m. Nothing is known about the effects of flooding during winter. Cutting underwater in autumn is a technique used to control *Typha* spp. (7) and warrants investigation.

Population maintenance. *L. peruviana* uses both seeds and vegetative growth to maintain its population. The soil seed bank is about 65 000/m^2. The growing season production for 1990/91 was estimated at about 450 000/m^2. Seeds had an average germination of about 80%, with an estimated viability of 99%.

The seed bank is relatively high when compared with seed bank figures for other wetlands (3), and is of the same order of magnitude as that obtained for *Juncus articulatus* in Australia (Brock unpublished data). The numbers fall short of the highest numbers recorded for dryland weed populations of up to 1 000 000/m^2 for *Amaranthus* spp. but are of the same order of magnitude.

Seedlings were only observed under the canopy where there had been some disturbance to the canopy. Seedlings were seen growing on mud away from shade.

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VOLUNTEER POTATO CONTROL IN ONIONS

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Summary. Fluroxypyr (methyl hepyl ester) applied sequentially, (300 g + 300 g and 225 g + 225 g a.i./ha, each 21 days apart), to potato plants in conjunction with other commercial onion herbicides significantly (P=0.01) reduced viable tuber number when applied at either tuber initiation or flowering, but not earlier than tuber initiation. Daughter tuber numbers from potato plants originating from mother tubers 50 g to 100 g were significantly (P=0.01) reduced by fluroxypyr. Fluroxypyr applied to autumn sown onions at the above rates significantly (P=0.05) decreased onion yield when applied at the five leaf stage of crop growth. Fluroxypyr did not significantly reduce total yield of spring-sown onions at any growth stage.

INTRODUCTION

Volunteer potatoes at a density of four plants/m^2 crops depresses onion yields, decreases bulb quality, and increases operating costs (2). A further problem is the production of viable daughter tubers that sustain volunteer potatoes for several seasons. This interferes with clean crop rotations as the carry-over volunteers are a source of pest and disease for future potato crops (1, 4, 6). Current chemical control measures use repeated applications of contact herbicides. In some cases, volunteer potatoes are hand pulled.

Overseas work (7) and previous research conducted by the Department of Primary Industry and Fisheries, Tasmania (8) has shown fluroxypyr (methyl hepyl ester) to control volunteer potatoes. In the studies reported here, the efficacy of fluroxypyr is further evaluated on volunteer potatoes. The tolerance of onion crops to fluroxypyr is also examined.

METHODS

Three experiments were conducted at Forthside Vegetable Research Station (FVRS) on red krasnozem soils in Northern Tasmania.

Effect of growth stage of potato plant on efficacy of fluroxypyr. Russett Burbank potato sets (50 g whole) were planted by hand in autumn at a density of four plants/m^2. A randomised complete block trial design examined the two sequential fluroxypyr treatments (Table 1) applied initially at three growth stages (pre-tuber initiation, tuber initiation, and flowering) of the potato plants, and replicated four times.

Table 1. Split fluroxypyr treatments used in experiments 1 to 3.

Treatment	Rate (g a.i./ha)	Timing of application (days apart)
1	300 + 300	21
2	225 + 225	21

Effect of mother tuber set size on the efficacy of fluroxypyr. Russett Burbank potato sets (25, 50, 75, 100 g whole) were planted by hand in autumn at a density of four plants/m^2. A randomised complete block trial design examined two sequential fluroxypyr treatments (Table 1) applied initially at tuber initiation, and replicated four times.

In both potato experiments, the same commercial herbicides used on the onion crops in the third experiment (see below) were also used on the potatoes to simulate an infestation of volunteer potatoes in an onion crop. The potatoes were harvested at the same time as the autumn sown onions. Number of potato daughter tubers from each treatment was recorded along with tuber quality. The daughter tubers were left to sprout in trays under glasshouse conditions (temperature range 16 to 25°C) to test for viability.

Onion crop susceptibility. Early Creamgold onions were planted in autumn 1992, and Regular Creamgold onions were planted in the spring of that year. A randomised complete block trial design examined two sequential fluroxypyr treatments (Table 1) applied at four growth stages (1, 3, 5, and 7 leaf) of the onion crop, and replicated four times. The use of other herbicides (propachlor, oxyfluorfen, methazole, ioxynil, ethofumesate) during onion crop growth was based on commercial decisions made by the FVRS manager. The physical appearance of the onion plants following application of each fluroxypyr treatment up until crop maturity was recorded. At harvest, onion bulbs were sorted into seven grades (<35, 35-40, 40-50, 50-60, 60-70, 70-80, and >80 mm) and the yield of each grade was recorded. A visual assessment was made for any bulb distortion or quality variations. Onion samples were sent for fluroxypyr residue analysis.

RESULTS AND DISCUSSION

Effect of growth stage of potato plant on efficacy of fluroxypyr. Application of both rates of fluroxypyr at tuber initiation and flowering resulted in significant (P=0.01) reduction in viable daughter tuber production (Fig. 1). There was no significant difference between the rates of fluroxypyr applied at these growth stages. The data indicated higher potato yields from plots treated at pre-tuber initiation with fluroxypyr compared with the nil application plots. This apparent anomaly indicated the other commercial herbicides used assisted in volunteer potato control; application of fluroxypyr at pre-tuber intiation resulted in insufficient healthy foliage to absorb the other herbicides applied shortly after fluroxypyr application.

Effect of mother tuber set size on the efficacy of fluroxypyr. Application of both fluroxypyr treatments significantly (P=0.01) reduced viable daughter tuber number from volunteer potato plants grown from the set sizes 50 g, 75 g, and 100 g (Fig. 2). Fluroxypyr treatment of plants grown from 25 g mother sets resulted in the least reduction of viable daughter tubers. Commercial onion herbicides and/or environment had the major effect on tuber production from mother tubers of 25 g or less. The larger the mother sets the more significant the effect of fluroxypyr. There were no significant differences between the two rates used.

In each of the nil treatments, potato plants grown from 25 g and 50 g sets produced significantly fewer tubers than plants grown from 75 g, and 100 g sets. Only the mother sets of 25 g produced fewer than 4 daughter tubers/m^2. Tuber numbers produced from 100 g mother set plants were reduced from more than 16 viable tubers/m^2 to just over 4 viable tubers/m^2 with these tubers now being less than 50 g. Although this would still result in onion crop yield reductions, volunteer potato infestation for the following season would be reduced. Fluroxypyr application to plants grown from each of the smaller set sizes showed viable daughter tuber reductions less than 1 viable tuber/m^2 (plants from 25 g mother sets).

The results of both potato experiments indicated that maximum volunteer potato control in onion crops was achieved using either of the sequential fluroxypyr treatments applied at tuber initiation or potato plant flowering. Minimum viable daughter tuber production was achieved applying either fluroxypyr treatment to potato plants grown from 25 g mother sets. This finding indicates the importance of the use of narrow pitch digging webs on potato harvesters to reduce the size of tubers falling through the digging web (5).

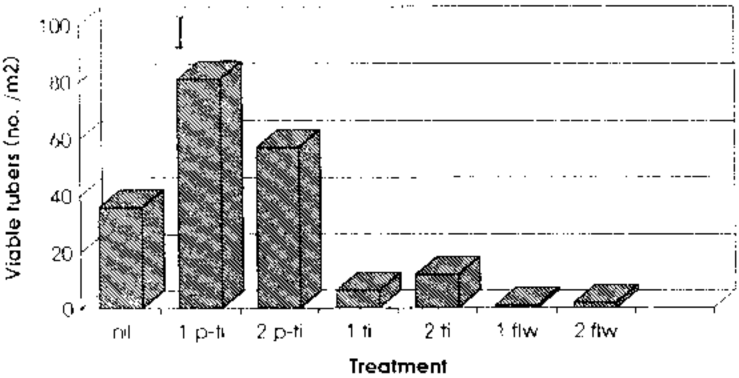

Figure 1. Efficacy of fluroxypyr treatments 1 and 2 applied to the potato plants at three different growth stages (p-ti = pre-tuber initiation, ti = tuber initiation, flw = flowering) on the viable number of daughter tubers produced compared with no fluroxpyr application (nil). Bar represents Fischers protected l.s.d. (P=0.01) for viable tuber number.

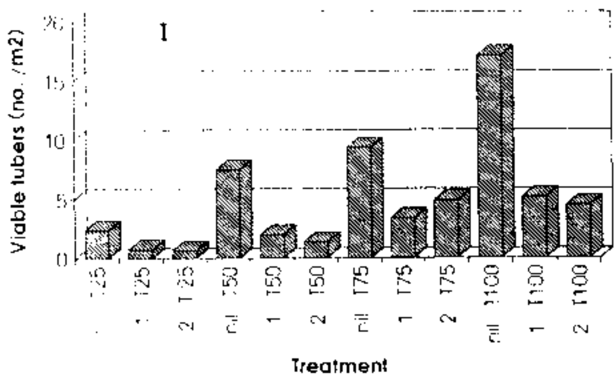

Figure 2. Efficacy of fluroxypyr treatments 1 and 2 applied to the potato crop originating from four different mother set sizes (T25 = 25 g, T50 = 50 g, T75 = 75 g, T100 = 100 g) on the number of daughter tubers produced compared with no fluroxypyr application for each set size (nil T25, nil T50, nil T75, and nil T100). Bar represents Fischers protected l.s.d (P=0.01) for viable tuber number.

Onion crop susceptibility. Fluroxypyr application resulted in mild to severe epinasty in the onion crops regardless of fluroxypyr application timing. Yield was significantly (P=0.01) decreased in the autumn sown onion crop with either rate of fluroxypyr applied at the 5 true leaf stage of the onion plants. No significant reductions in total onion yield were found on the spring sown crops, however there was a significant (P=0.01) reduction of onions larger than 80 g. Considering total yield was not affected by any of the treatments, this indicates a smaller bulb size in the marketable (30 to 80 g) size range. No significant reductions were found in plots treated at the 7 true leaf stage. This was probably because the onion plant had already reached its maximum yield by this late stage. Preliminary visual observations of the onions found no bulb distortions or quality variations. Chemical analysis of the treated bulbs found no detectable residues of fluroxypyr for any of the treatments.

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CEREAL COVER CROPS FOR VEGETABLE PRODUCTION IN TASMANIA

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Summary. Cereal cover crops, rye and barley were compared to a no-mulch treatment in onions, broccoli and sweet corn. Rye cover crops achieved a 75% reduction in weed biomass 50 days after sowing. In broccoli, an early rye cover crop maintained low weed biomass through the life of the crop (130 days) with only a slight reduction in yield. Both onions and sweet corn plant establishment was affect by the cover crops primarily due to sowing difficulties.

INTRODUCTION

Weed control is a major component in vegetable production, with cultivation and the use of herbicides as the main control methods employed. Any reduction in either of these control methods will be economically beneficial and in the case of cultivation better for the soil structure. The use of cover crops can reduce both the use of cultivation and herbicides by decreasing weed populations through chemical and physical suppression by the mulch (4, 6). Residues of cereal rye, *Secale cereale*, have been shown to provide up to 100% weed control (1, 2, 4, 5, 6, 7) with no reduction in crop yield.

METHODS

A series of experiments was established to evaluate cereal rye and barley, *Hordeum vulgare*, as dead mulches in providing weed control in onions, broccoli and sweet corn. The cover crops were sown on 8 September 1992, with barley cv. Franklin sown at 80 kg/ha and cereal rye sown at 160 kg/ha. No fertiliser was added at sowing.

A split plot design with four replications was used in all the experiments, with the main plots being the type of cover crop (no-mulch, barley or rye) and the sub plot consisting of the mulch management. The sub plots (3.2x6 m) consisted of (a) mulch killed at planting (early), (b) mulch killed 1-2 weeks after planting or sowing (mid) and (c) mulch killed off 3-5 weeks after planting or sowing (late). The no-mulch plots received the same herbicides that were used to kill the barley and rye.

Onions cv. Cream Gold were sown at 120 seeds/m^2 with 500 kg/ha 14:16:11 fertiliser on 12 October 1992. The early mulch treatments were sprayed off using 0.54 g a.i./ha glyphosate in 250L/ha water volume on 24 October 1992. Middle and late cover crops were killed off using 0.424 kg a.i./ha fluazifop (butyl ester) in 250 L/ha water volume on 13 November 1992 and 28 November 1992 respectively. The onion part of the experiments was terminated on 15 December 1992.

Broccoli cv. Greenbelt was planted on 16 November 1992 at 3.75 plants/m^2 with fertiliser 13:14:13 pre drilled at 500 kg/ha. Early cover crop treatment was killed off on 14 November 1992 with 0.72 kg/ha glyphosate. On 28 November 1992, 0.424 kg/ha fluazifop was applied to the middle cover crop treatments. The late treatments had 0.12 kg/L glyphosate applied through a wiper on 2 December 1992. All no-mulch plots had glyphosate at 0.12 g/L applied through a hand held wiper. Broccoli was harvested between 11 and 18 January recording head weights and assessing marketability.

Sweet corn cv. Sno Sweet was sown on 14 November 1992 at 8 seeds/m^2 with fertiliser 14:15:13 at 500 kg/ha. Early and late cover crops were killed off with 0.72 kg/ha glyphosate on 14 November 1992, or by wiper using 0.12 kg/L glyphosate on 2 December 1992 respectively. There was no middle cover crop treatment for sweet corn. The late barley cover crop treatments and no cover crop treatments had 1.5 kg a.i./ha MCPA (dimethyl amine salt) and 10 g a.i./ha dicamba applied interrow on 22 December 1992. The sweet corn was harvested between 24 March 1993 and 29 March 1993 with individual cob weight and marketability being recorded.

Plant establishment counts were conducted on 15 December 1992 for onions and 11 January for the broccoli and sweet corn. Both weed dry matter and cover crop dry matter was assessed through the trial on 27 October 1993, 12 February 1993, 12 March 1993 and 30 March 1993.

RESULTS AND DISCUSSION

Plant establishment in onions and sweet corn was significantly (P=0.01) affected by the different levels of mulch. In onions, only the no-mulch plots and the early barley treatments gave commercially acceptable plant stands (Table 1). All late treatments and rye treatments, significantly (P=0.01) reduced corn plant numbers. This was due to machinery planting problems rather than the direct effect of the mulch on corn germination. The effects of low plant establishment numbers in the onions and the sweet corn was reflected throughout the trial and was the primary influence on yield in sweet corn. Neither onion or sweet corn yield data is presented. There were no significant differences in plant establishment levels in the broccoli.

Table 1. Crop establishment numbers per m^2 of onions, broccoli and sweet corn under different mulch regimes

	Onions			Broccoli			Sweet corn	
	Early	Mid	Late	Early	Mid	Late	Early	Late
No-mulch	50.5	44.3	51.5	2.53	1.23	1.81	7.98	4.52
Barley	40.3	22.0	20.0	1.98	1.77	1.81	7.83	1.36
Rye	29.5	18.8	11.3	2.09	1.63	1.60	4.07	0.71
l.s.d. (P=0.01)	13.5			n.s.			3.19	

Broccoli yield was significantly (P=0.01) greater in all early treatments than any mid or late treatments (Fig. 1). Though the yield in the early rye plot was significantly (P=0.01) lower than the early no-mulch treatment, no herbicides were used in the rye plots. The no-mulch treatments had a post-emergent herbicide application. A better result may be achieved with broccoli by having the rye mulch killed prior to planting as in soybeans, rye mulch killed off two weeks prior to sowing, gave better yields than rye killed off at sowing (4). This could also apply for sweet corn and onions, as long as sowing difficulties can be overcome.

Fifty days after the sowing of the mulches, the barley and rye plots had significantly reduced dry weight of all species present (Fig. 2). Total dry weight was significantly reduced by 75% (P=0.01) in the rye mulch. However there was no difference between mulches in plant numbers (Fig. 2). The main species present, in order of importance were wireweed, *Polygonum* *aviculare*, field bindweed, *Convolvulus arvensis*, spurry, *Spergula arvensis*, speedwell, *Veronica hederifolia*, and chickweed, *Stellaria media*. Barnes and Putman (1) also achieved a reduction of this magnitude with a rye mulch without reducing weed germination. Others (5) found that a rye mulch gave biomass reductions in both broadleaves and grasses, where forage oats only gave a reduction in broadleaf weeds biomass. As broadleaves were the only weeds present in magnitude in this experiment, the relative effectiveness of rye and barley on grass weed biomass production can not be made.

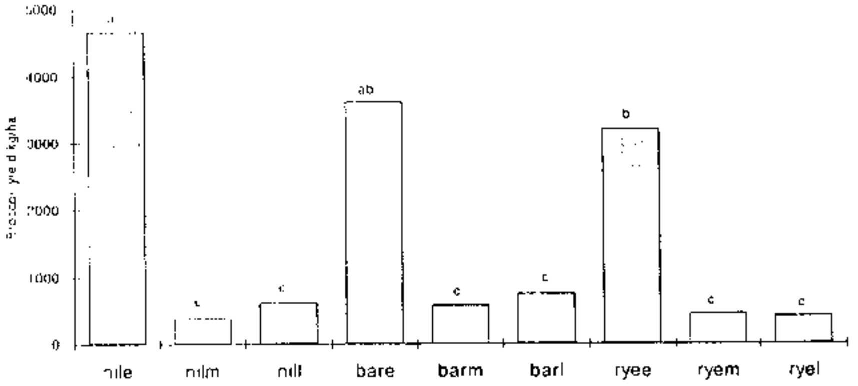

Figure 1. Yield of broccoli under different mulch regimes (nile = no-mulch early, nilm = no-mulch. mid, nill = no-mulch late, bare = barley early, barm = barley mid, barl = barley late, ryee = rye early, ryem = rye mid and ryel = rye late). Means followed by the same letter are not significant at the P=0.01 level as determined by Fisher's protected l.s.d.

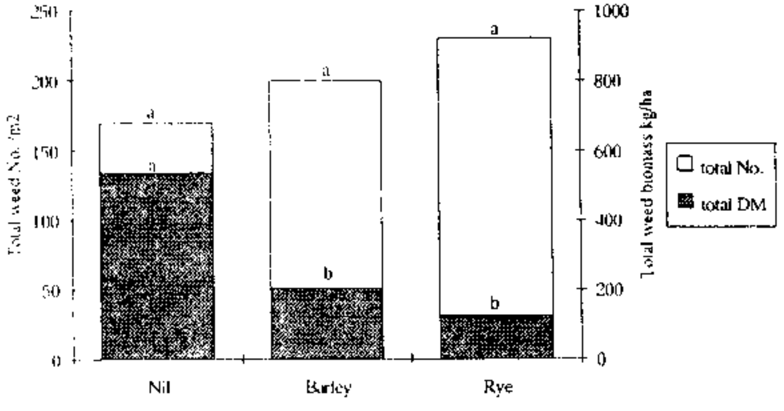

Figure 2. Total weed numbers and weed biomass (DM), 50 days after the sowing of the mulches prior to herbicide application. Means within each variable followed by the same letter are not significant at the P=0.01 level as determined by Fisher's protected l.s.d..

At broccoli harvest each mulch type was significantly different (P=0.01) from each other, with rye > barley > no-mulch (Fig. 3). The differences between the rye and barley could be due to either the initial sowing rates, 160 kg/ha vs 80 kg/ha or that rye does not break down as quickly. The early rye treatment maintained low weed biomass levels for 130 days (until harvest) being significant (P=0.05) from all other treatments except the early barley treatment. The other rye treatments did not achieve the same reductions in weed biomass. The cause is most probably in the method of killing off the mulch with the mid treatments using fluazifop which has no effectiveness against broadleaves and the late treatments having glyphosate applied through a wiper which would be above the weeds height. This indicates that the reduction in weed biomass had more to due with a physical effect from the mulch than an allelopathic (chemical) effect. While other studies of rye mulch have indicated that mulch levels need to be in excess of 4000 kg/ha to reduce weed biomass for 30-60 days (3), in this experiment, rye mulch levels reduced weed biomass until broccoli harvest (130 days) with mulch levels around 3000 kg/ha (Fig. 3).

The different levels of weed biomass for the early treatments (nile, bare and ryee) (Fig. 3) are the inverse to the yield of broccoli (Fig. 1). The mulch levels from these treatments corresponded to the yield. This indicates that the level of mulch present had a direct effect on yield.

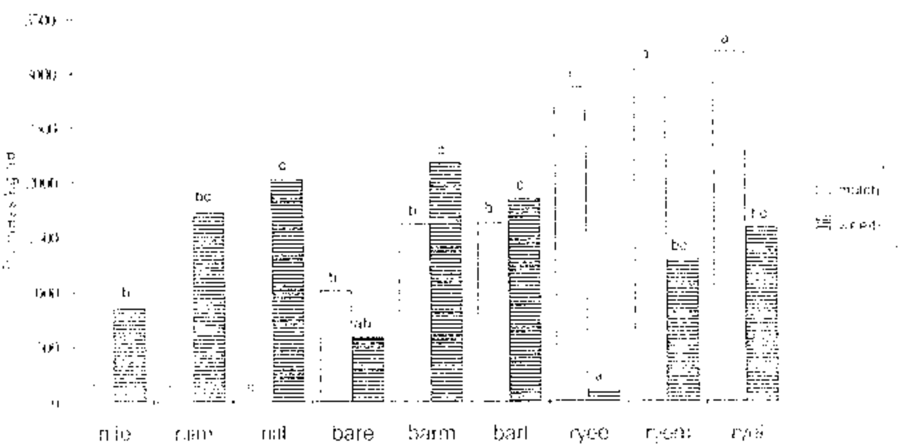

Figure 3. Weed and mulch biomass levels at broccoli harvest under different mulch regimes (nile = no mulch early, nilm = no-mulch. mid, nill = no-mulch late, bare = barley early, barm = barley mid, barl = barley late, ryee = rye early, ryem = rye mid and ryel = rye late). Means within each variable followed by the same letter are not significant at the P=0.01 level for mulch and P=0.05 level for weed biomass as determined by Fisher's protected l.s.d..

While some reduction in yield occurred in all crops studied, the role of cereal cover crops to reduce weed biomass for up to 130 days with no added herbicides holds promise of using these mulches to reduce inputs of cultivation and herbicides into our vegetable cropping systems.

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THE TOLERANCE OF FOUR FIJIAN SUGARCANE VARIETIES TO PRE-EMERGENT AND POST-EMERGENT HERBICIDES

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Summary. Field studies tested the tolerance of Mana, Kaba, Mali and Ragnar sugarcane varieties to varying rates of 3 pre- and 3 post-emergent herbicides commercially available in Fiji.

Pre-emergent treatments with 5, 10 and 15 L/ha of Cane Spray 333 (7.5% dicamba + 30% 2,4-D) or with 2, 4 or 6 kg/ha of Diuron 80 (80% diuron) or Velpar K4 (13.2% hexazinone + 46.8 % diuron) caused little or no damage to any variety. Kaba and Ragnar showed slight susceptibility to 15 L/ha of Cane Spray 333 but recovered within 4 weeks, but no herbicide or rate significantly affected yield when harvested at 14 months.

Post-emergent treatments with 4, 8 or 12 L/ha of Asulox 40 (40% asulam) caused no significant damage except at the higher rates to Mali and Kaba. 1, 2, or 3 L/ha of Actril DS (10% ioxynil + 60% 2,4-D) only caused damage to Ragnar at the higher rates. 2, 4, or 6 L/ha of Tota-col (10% paraquat + 30% diuron) caused severe damage to all varieties.

Most weeds (apart from grasses with Velpar K4) can be safely controlled at these rates by either the pre- or post-emergent herbicides tested.

INTRODUCTION

Early in the 1950, Nolla found different Sugarcane varieties to have different response to 2,4-D (2), therefore, he classified the Sugarcane varieties into four categories, susceptible, moderately susceptible, slightly susceptible and resistant. Rochecouste discovered in Mauritius that there were significant differences among sugarcane varieties in the resistance to the herbicide Dalapon, hence, he sorted the sugarcane varieties highly susceptible, susceptible and moderately susceptible into three categories (3). Millhollon and Matherne (1) cited that sugarcane variety N: Co 310 was more resistant to Diuron than C.P. 44-101 and C.P. 52-68. Herbicide application in cane field was not so common in many of the Fiji Sugarcane farmers. However, it is the tendency that chemical weed control will be the major measurement due to its cheapness and shortage of labour in the situation of Fiji cane belt.

METHODS

Field trial was conducted in Drasa Lautoka, Fiji, from May 1989 to July 1990 on an oxisol soil. The four commercial sugarcane varieties were Mana, Mali, Kaba and Ragnar.

Ten treatments involving three herbicides, Cane Spray 333, which is the mixture of 7.5% Dicamba and 30% 2,4-D, Diuron 80, which contains 80% of Diuron and Velpar K4, which is the mixture of 13.2% Hexazinone and 46.8% Diuron. The application rates were 5, 10 and 15 L/ha. in Cane Spray 333 and 2, 4, and 6 kg/ha for Diuron and Velpar K4. In addition, one control treatment without herbicide application was also included. The pre-emergent chemicals were sprayed one week after sugarcane planting.

Three products, Asulox 40 containing 40% Asulam; Actril DS, which is the mixture of 10% Ioxynil and 60% 2,4-D and Tota-Col which contains 10% paraquat and 30% Diuron were used in the post-emergent herbicide trial. The application rates were 4, 8 and 12 L/ha of Asulox 40, 1, 2 and 3 L/ha of Actril DS and 2, 4 and 6 L/ha of Tota-Col. The post-emergent chemicals were applied 6 weeks after cane planting.

The experimental design was two-fold split plot design with three replicates, each plot contains of 4 rows (1.37 row spacing) in a length of 5 metres.

RESULTS AND DISCUSSION

Tolerance of varieties to pre-emergent herbicides

Table 1 indicates that all three pre-emergent herbicides caused no or very low phytotoxicity in four varieties tested even in high rate.

Table 1. Tolerance (A) and the recovery time from phytotoxic effect (B) of sugarcane varieties to pre-emergent herbicides in Fiji

Variety	Cane Spray 333						Diuron 80						Velpar K4					
	5 L/ha*		10 L/ha		15 L/ha		2 kg/ha		4 kg/ha		6 kg/ha		2 kg/ha		4 kg/ha		6 kg/ha	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Mana	1**	-	1	-	1	-	0	-	0	-	1	-	1	-	1	-	1	-
Mali	1	4***	2	4	2	4	1	-	2	4	2	4	1	4	1	4	2	4
Kaba	1	-	2	4	3	4	1	-	1	-	2	4	1	-	1	-	1	-
Ragnar	1	-	2	4	3	4	1	-	1	-	1	-	0	-	1	-	1	-

* Rate in quantities of product per hectare.

** O = Resistant; 1, 2, 3 = Slightly susceptible; 4, 5, 6 = moderate susceptible; 7, 8, 9 = Highly susceptible; 10 = Dead

\- No phytotoxic effect

*** Number of weeks for the recovery

Varieties KABA and RAGNAR were slightly susceptible to Cane Spray 333 at high rate of 15 L/ha but recovered at 4 weeks after application (Table 1). Yeh (4) cited that for the 2,4-D injury in the F series (F146 to F178), the recovery period for pre-emergence was 8 weeks, while only 4 weeks for these Fiji commerical varieties. The weed control effect of the three products was also observed (Table 2), both Cane Spray and Velpar K4 could control effectively the broadleaf and the creeper weeds at least 6 weeks. Less effectiveness was observed from Cane Spray and Diuron when used for control of the gramineae weeds.

Pre-emergent herbicide application neither affect stalk population nor stalk length in all four varieties tested. As a result, no significant differences between treatments in cane and sugar production have been found (Tables 3 and 4). For Kaba variety, significant differences between treatments were found in herbicides tested, however, the differences could not be attributed to toxicity effect.

Table 2. Efficacy of common pre-emergent herbicides on weed control at 6 weeks after application

Herbicides	Rate	% Control		
		Broadleaf	Creeper	Gramineae
Cane Spray	5 L/ha	73	76	-
Diuron	2 kg/ha	56	52	19
Velpar K4	2 kg/ha	70	-	46

Table 3. Effect of pre-emergent herbicide application on cane yield (t/ha) of four varieties planted in an oxisol soil

Variety	Cane Spray 333 (L/ha)					Diuron 80 (kg/ha)					Velpar K4 (kg/ha)				
	0	5	10	15	CV%	0	2	4	6	CV%	0	2	4	6	CV%
Mana	165	179	188	146	15 NS	165	149	162	153	29 NS	165	127	145	132	35 NS
Mali	141	150	148	134	18 NS	141	117	134	143	20 NS	141	169	130	164	18 NS
Kaba	128	97	143	121	18 5%	128	98	172	130	18 1%	128	155	129	145	9 5%
Ragnar	126	121	117	126	16 NS	126	106	136	121	13 NS	126	111	130	116	12 NS

Table 4. Effect of pre-emergent herbicide application on sugar yield (t/ha) of four varieties planted in an oxisol soil

Variety	Cane Spray 333 (L/ha)					Diuron 80 (kg/ha)					Velpar K4 (kg/ha)				
	0	5	10	15	CV%	0	2	4	6	CV%	0	2	4	6	CV%
Mana	22	24	27	20	19 NS	22	21	21	22	13 NS	22	17	20	18	34 NS
Mali	18	14	16	14	16 NS	18	12	15	16	21 NS	18	16	14	16	18 NS
Kaba	20	14	14	27	17 NS	20	14	19	25	18 1%	20	21	19	20	9 NS
Ragnar	19	19	17	17	15 NS	19	17	21	20	13 NS	19	18	18	18	11 NS

Tolerance of varieties to post-emergent herbicides

Due to Tota-Col containing Paraquat which is non-selective, very serious phytotoxicity up to grade 9 was observed in all four varieties under test (Table 5). Most of the young Aillers were destroyed permanently by Tota-Col. Next to Tota-Col, Ragnar variety was also moderate susceptible to Actril DS when application rate was in medium to high level. Mali variety was also slightly to moderate susceptible to Asulox. Most of young cane was killed by Tota-Col which destroyed the crop establishment permanently. However, replanting for these plots for maintaining enough surviving number of sugarcane for the trials. Despite severe damage to sugarcane by Tota-Col, Mana, Kaba and Ragnar recovered from phytotoxicity at 4 weeks after application, while it took 8 weeks for Mali to recover (Table 5).

Yeh (4) reported that for F varieties in Taiwan, it took 6 weeks in post-emergent chemicals application for all injury symptoms to recover in the sensitive varieties.

Similar to pre-emergent herbicides, the cane growth neither in stalk population nor in stalk length was affected by any of the post-emergent herbicides. The plant crop of this trial was harvested at 14 months. The subsequent cane and sugar yield data indicated that except Mana variety applied with Actril DS, no adverse effect of herbicide application was observed (Tables 6 and 7). The highest rate of Actril DS of 3 L/ha applied on Mana tended to suppress yield. However, further verification is needed.

Table 5. Tolerance (A) and the recovery time from phytotoxic effect (B) of sugarcane variety to pre-emergent herbicides in Fiji

Variety	Asulox 40						Actdril DS						Tota-Col		
	4 L/ha*		8 L/ha		12 L/ha		1 L/ha		2 L/ha		3 L/ha		1 L/ha	2 L/ha	3 L/ha
	A	B	A	B	A	B	A	B	A	B	A	B	A	A	A
Mana	0**	-	2	4	3	4	0	-	1	4	3	4	9	9	9
Mali	3	8***	3	8	4	8	1	8	2	8	3	8	9	9	9
Kaba	1	4	3	4	5	4	1	4	2	8	3	8	9	9	9
Ragnar	1	4	2	4	2	4	2	4	4	4	5	5	9	9	9

* Rate in quantities of product per hectare.

** O = Resistant; 1, 2, 3 = Slightly susceptible; 4, 5, 6 = moderate susceptible; 7, 8, 9 = Highly susceptible; 10 = Dead

\- No phytotoxic effect

*** Number of weeks for the recovery

Table 6. Effect of post emergent herbicide application on cane yield (t/ha) of four varieties planted in an oxisol soil

Variety	Asulox 40 (L/ha)				Actril DS (L/ha)				Tota-Col (L/ha)			
	0	4	8	12	0	1	2	3	0	2	4	6
Mana	149	155	123	150	149	164	147	101	149	169	114	130
Mali	157	135	149	166	157	165	137	153	157	134	157	137
Kaba	150	143	132	100	150	143	137	135	150	141	143	151
Ragnar	140	129	144	128	140	117	137	123	140	110	136	141

Table 7. Effect of post-emergent herbicide application on sugar yield (t/ha) of four varieties planted in an oxisol soil

Variety	Asulox 40 (L/ha)					Actril DS (L/ha)					Tota-Col (L/ha)				
	0	4	8	12	CV%	0	1	2	3	CV%	0	2	4	6	CV%
Mana	20	23	15	20	16 5%	20	23	20	13	20 1%	20	25	16	18	32 NS
Mali	18	15	18	18	22 NS	18	18	15	16	25 NS	18	14	19	13	21 5%
Kaba	20	21	16	15	23 NS	20	22	21	19	18 NS	20	20	20	22	16 NS
Ragnar	19	19	20	18	17 NS	19	16	20	18	18 NS	19	16	20	20	12 NS

The results obtained from this trial imply that except Tota-Col, the application of some post-emergent herbicides could cause phytotoxicity to growth at the young cane stage, but once the crop recovered, the final yield will not be affected. Similar results were found by Yeh (5), he cited that although different varieties responded differently in tolerance to herbicides yet such physiological character was not related to sugar accumulation of cane.

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WEED CONTROL IN SOD-SEEDING SOYBEAN IN JAPAN

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Summary. Efficacy was not reduced by mixing glufosinate or diquat-paraquat with soil applied herbicides such as alachlor, metolachlor, linuron, prometryn and trifluralin. The efficacy against weeds of glyphosate combined with soil applied herbicide such as trifluralin reduced slightly as compared with glyphosate alone. Efficient weed control was obtained by sequential application, namely preplant treatment of foliar applied herbicide followed by postplant treatment of soil applied herbicide or combined application of postplant treatment using both types of herbicides in sod-seeding cultivation of soybean.

INTRODUCTION

Double cropping, of wheat and soybean is popular in the rotational upland fields in Japan. In June (the rainy season in Japan) soybean is sown soon after harvesting of wheat using sod-seeding cultivation in order to use mechanical seeder effectively (1,2). Experiments on the herbicidal efficacy to weeds and injury of herbicides to soybean were conducted to establish an efficient weed control system for sod-seeding cultivation of soybean.

METHODS

Experiment 1. Efficacy of foliar applied herbicides mixed with soil applied herbicides was investigated. Herbicides used were as follows:

Foliar applied herbicides: glyphosate, glufosinate, diquat-paraquat
Soil applied herbicides: alachlor, metolachlor, linuron, prometryn, trifluralin, prometryn-metolachlor.

These herbicides were applied at growing stage of *Digitaria ciliaris* (Retz.) Koeler and *Amaranthus patulus* Bertoloni. Concrete pots of 50x50 cm filled with volcanic ash soil to 30 cm depth were used in this experiment with 3 replications.

Experiment 2. Injury of herbicides to soybean was investigated. Soybean, cultivar Tachinagaha was sown with no soil cover or 3 cm depth of soil cover using the same concrete pots as in Experiment 1 with 3 replications. Herbicides used were as follows:

alachlor, metolachlor, linuron, prometryn, trifluralin, prometryn-metolachlor, glyphosate, glufosinate, diquat-paraquat.

Experiment 3. Efficacy and injury of herbicides to sod-seeding soybean were investigated using rotational upland field continuing sod-seeding culture during 3 years. Soybean, cultivar Tachinagaha was sown on 19 June 1990. Five levels of herbicide application method were designed as follows:

a. Foliar application of glufosinate 925 g/ha before seeding
b. Soil application of prometryn-metolachlor 0.8+1.2 kg/ha after seeding

c. Foliar application of glufosinate before seeding followed by soil application of prometryn-metolachlor after seeding
d. Combined application of glufosinate mixed with prometryn-metolachlor after seeding
e. Untreated.

This experiment was carried out at a rotational upland field of the National Agriculture Research Center. Plot size was 7.2x2 m with 3 replications.

RESULTS AND DISCUSSION

Effect of soil applied herbicides mixing with foliar applied herbicides on the herbicidal efficacy to growing weeds is shown in Table 1. Herbicidal efficacy was not reduced by mixing glufosinate or diquat-paraquat of foliar applied herbicides with soil applied herbicides such as alachlor, metolachlor, linuron, prometryn, trifluralin and combination of prometryn-metolachlor. The efficacy against *Amaranthus patulus* of glyphosate combined with soil applied herbicide such as trifluralin was slightly reduced compared with glyphosate alone.

Table 1. Effect of soil applied herbicides mixing with foliar applied herbicides on the efficacy to growing weeds

Foliar applied herbicide	Dosage (kg/ha)	Weed	% Weed control						
			Al[1]	Met	Li	Pro	Tri	Pro-mt	No mix
Glyphosate	1.04	D[2]	100	100	100	100	100	99	100
		A	99	100	100	95	90	100	100
Glufosinate	0.56	D	100	100	100	100	95	100	100
		A	100	100	100	100	100	100	100
Diquat-paraquat	0.42 +0.30	D	88	80	97	91	87	95	73
		A	100	100	100	100	100	100	100

Footnotes: [1] Al : alachlor 2.58 kg/ha, Met : metolachlor 1.8 kg/ha, Li : linuron 1.0 kg/ha, Pro : prometryn 1.0 kg/ha, Tri : trifluralin 1.34 kg/ha, Pro-mt : prometryn-metolachlor 0.8+1.2 kg/ha, No mix : no mixing.
[2] D : *Digitaria ciliaris*, A : *Amaranthus patulus*

Effect of herbicides on emergence and early growth of soybean is shown in Table 2. Foliar applied herbicides, namely glyphosate, glufosinate and diquat-paraquat, caused reduced emergence of soybean seeded with no soil cover. As shown in Table 2, the number of emergence of soybean was reduced 13-41% compared with untreated plot. Adverse effect on early growth of soybean seeded with no soil cover was not observed in the plots of application of foliar applied herbicides. Soil applied herbicides such as trifluralin and prometryn caused a slightly reduced emergence of soybean seeded with no soil cover, and delay of growth was observed in the plots of alachlor, metolachlor and prometryn-metolachlor application. In the plots 3 cm soil cover condition, the adverse effect on emergence or early growth of soybean was not observed by foliar applied herbicides, but alachlor, metolachlor and prometryn-metolachlor reduced early growth of soybean due to heavy rainfall soon after herbicide treatment.

Efficacy and injury of herbicides to sod-seeding cultivation of soybean was shown in Table 3. A poor herbicidal efficacy to weeds was observed in the single application of foliar applied herbicide before seeding or soil applied herbicide after seeding. Efficient weed control was obtained by sequential application, namely preplant treatment of foliar applied herbicide followed by postplant treatment of soil applied herbicide or combined application of postplant treatment using both types of herbicides. Herbicide injury to soybean was not observed even with 1 cm soil cover in this experiment. More experiments including a method for avoiding herbicide injury to no or shallow soil cover, a method for convenient herbicide application etc. are necessary for sod-seeding in order to establish an efficient weed control system.

Table 2. Effect of herbicides on emergence and early growth of soybean

Herbicide	Dosage (kg/ha)	Emergence (%)	Stem length (cm)	No. of leaf/plant	Top fresh weight (g/plant)
			0 cm of soil cover		
Alachlor	2.58	100	21.8	4.6	8.8
Metolachlor	1.8	100	22.0	4.5	8.2
Linuron	1.0	92	24.0	5.0	11.9
Prometryn	1.0	88	23.8	5.3	11.2
Trifluralin	1.34	87	23.8	5.1	11.5
Prometryn-metolachlor	0.8 + 1.2	96	22.0	4.9	9.7
Glyphosate	2.05	77	24.0	5.0	12.4
Glufosinate	0.93	59	23.5	5.1	13.7
Diquat-paraquat	0.7 + 0.5	87	23.0	5.0	12.0
Untreated	-	100	25.3	5.1	12.0
l.s.d. P=0.05		13.5	n.s.	0.4	2.1
			3 cm of soil cover		
Alachlor	2.58	100	21.6	5.0	11.0
Metolachlor	1.8	100	21.6	4.8	11.2
Linuron	1.0	100	24.1	5.1	13.3
Prometryn	1.0	91	24.8	5.5	15.0
Trifluralin	1.34	100	24.8	5.4	15.0
Prometryn-metolachlor	0.8 + 1.2	91	21.4	5.0	11.7
Glyphosate	2.05	100	25.9	5.3	15.7
Glufosinate	0.93	100	24.4	5.3	16.3
Diquat-paraquat	0.7 + 0.5	100	25.1	5.3	16.9
Untreated	-	100	24.6	5.2	14.3
l.s.d. P=0.05		n.s.	2.6	0.3	3.7

Table 3. Efficacy and injury of herbicides to sod-seeding cultivation of soybean

Plot	Weed control (%)	Soybean			
		1 cm of soil cover		3 cm of soil cover	
		Stem length (cm)	Top fresh wt (g/plant)	Stem length (cm)	Top fresh wt (g/plant)
a[1]	44	40	23.2	46	25.2
b	42	43	21.9	48	25.4
c	98	42	25.1	45	27.0
d	99	46	28.0	49	29.2
e	0	43	20.7	46	22.6
l.s.d. P=0.05	51	n.s.	n.s.	n.s.	n.s.

Footnote: [1] a,b,c,d: See Experiment 3 in METHODS.

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MODELLING THE FATE OF BROME GRASS IN THE LUPIN/WHEAT ROTATION

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Summary. This paper describes a simulation model for brome grass that gives an indication of the seed bank dynamics under different weed control regimes in both the lupin phase and the wheat phase. The model shows that simazine and a grass selective herbicides are essential to reduce the weed seed bank during the lupin phase so that the yield potential of the following wheat crop is not reduced. Brome grass seed bank is, however, replenished in the wheat phase and delayed seeding did not reduce the weed seed bank significantly. At present there is little information on the impact of the seeding operations on the seed bank and validation of the seed decay curve is necessary.

INTRODUCTION

The lupin-wheat rotation is a very productive cropping system on the sand plain soils of Western Australia. With the adoption of minimum tillage for wheat production and early seeding, brome grass has become a dominant weed, as there are no selective herbicides registered for its control in wheat. At present farmers are relying on grass selective herbicides in the lupin phase to reduce brome grass seed carry-over into the wheat phase. However, it is important to incorporate control options into an integrated program for the long term sustainability of the lupin-wheat rotation. Modelling the impact of control techniques on weed seed production and carry-over will be valuable for the development of an integrated weed control program.

A simulation model of the life cycle of brome grass was used to study the effect of varying the degree of kill through the use of chemicals and delayed seeding on the long term seed population trends in the lupin-wheat cropping rotation.

MODEL

The simplified life cycle model for brome grass was adapted from a model for wild oats (3). This includes a proportion of the seed bank which produced mature plants in the crop , the number of seeds produced and the mortality of seeds in the seed bank. The model was programmed in Microsoft Excel and runs on a PC.

We have assumed that the seed decay curve is sigmoidal (Fig. 1). The depletion of the majority of the seed bank occurs within 12 months following seed production (1). Seed decay was assumed to be minimal immediately following production in December due to innate and enforced dormancy. The innate dormancy of *Bromus* sp is short and generally does not extend into the winter months (2).

Brome grass seed production was described by a hyperbolic, non-linear function of weed density (pers comm. Cheam). Seed production approached an upper limit of 6500 seeds/m^2 as weed density increased to 1000 plants/m^2 (Fig. 2).

Assumptions were also made about efficacy of the herbicides used in the model; simazine (75%), grass selective herbicide in lupin phase (95%) and herbicides in wheat (70%).

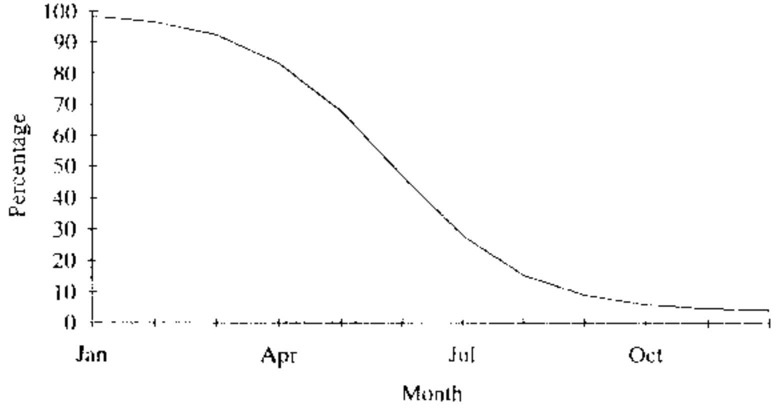


Figure 1. Relative decay of brome grass seed following production in December.

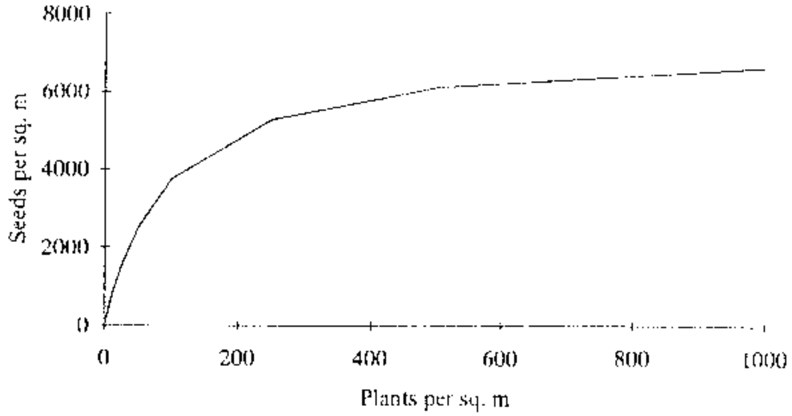
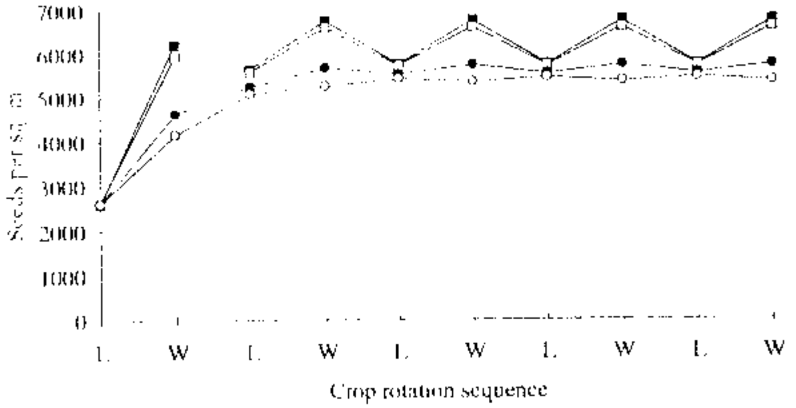


Figure 2. Relationship between brome grass seed production and weed density

RESULTS AND DISCUSSION

The main effect of not applying a grass selective herbicide in the lupin phase was a rapid increase in the brome grass seed bank in the first two years of the rotation. The initial seed bank was set at 1000 seeds/m^2. At the end of the first lupin crop in which simazine only was applied, the seed bank had increased to 3000 seeds/m^2. In contrast, the seed bank was reduced to 300 seeds/m^2 at the end of the first lupin crop when both simazine and a grass selective herbicide were applied.

a) simazine in lupin



b) simazine plus grass selective herbicide in lupin.

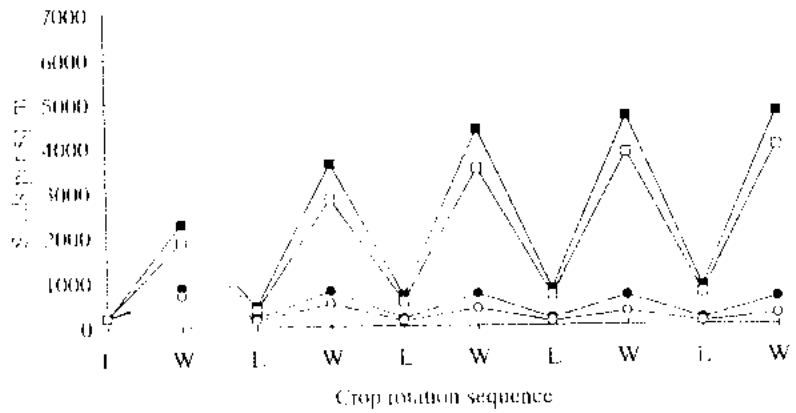


Figure 3. Effect of herbicides in wheat and delayed seeding of wheat on brome grass seed bank in the lupin (L)-wheat(W) rotation.
(■ :early sown wheat, no herbicide; □ :late sown wheat, no herbicide; ● :early sown wheat, plus herbicide; O :late sown wheat, plus herbicide).

Replenishment of the seed bank occurred in the wheat phase. Following the depletion of the seed bank during the lupin crop where simazine and a grass selective herbicide were used, the seed bank was replenished in the following wheat phase to greater than 2000 seeds/m^2. However, adopting the use of a herbicide with 70% efficacy in the wheat phase maintained the weed seed bank at about 500 seeds/m^2 in the following wheat year. The impact of delayed seeding of wheat was a slight reduction in the weed seed bank relative to early sowing.

The model indicates that the best management practice to ensure that the brome grass seed bank does not increase to the maximum level and impact on wheat production is the use of grass selective herbicides in the lupin phase. The use of chemicals or cultural practices in the wheat phase were not essential. However, the grass selective herbicides used in lupins are effective on both brome grass and annual ryegrass. While targeting control of brome grass, annual ryegrass populations resistant to the grass selective herbicides could develop and the model does not incorporate the impact of the continuous herbicide usage on the altering weed spectrum. Hence we need to reduce the reliance on grass selective herbicides for brome grass control and develop an integrated approach to weed control which is economically sustainable. The brome grass seed bank model will be valuable for the development of an integrated weed control program. Validation of the model is not complete. At present there is little information on the impact of the seeding operations on the seed bank and weed establishment. Validation of the seed decay curve is also necessary.

ACKNOWLEDGEMENTS

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METRIBUZIN AS A BROAD-LEAVED POST-EMERGENCE HERBICIDE FOR NARROW LEAF LUPINS

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Summary. Metribuzin has been suggested as an alternative herbicide to use post-emergence on triazine tolerant lupin cultivars to control broad-leaved weeds. In 1992 a series of field trials were conducted in lupin growing areas of the West Australian wheatbelt to determine both the tolerance and efficacy of metribuzin use post-emergence. Sites chosen had doublegee, wild radish, fumitory plus a variety of grasses surviving the simazine applied immediately before seeding (IBS). The tolerant variety Gungurru allowed good selectivity with metribuzin. Application rates of 70 g/ha a.i. controlled small doublegee and radish. Large weeds required 100 g/ha for control.

INTRODUCTION

Simazine is routinely applied immediately before seeding (IBS) to narrow leaf lupin, *Lupinus angustifolius*, crops as the main herbicide to control the majority of weeds in Western Australia. Post emergence broad-leaved weed control remains a problem in certain situations. Previous work has shown that the variety Gungurru is more tolerant to triazine herbicides than Danja and some other, older varieties (1). Merrit is also a triazine tolerant cultivar.

The current herbicide options for post-emergence broad-leaved weed control are either simazine top-up or diflufenican. There is little leaf uptake of simazine and moist soil is required for the herbicide to work effectively. Large weeds, especially transplants, are difficult to control as the simazine remains near the surface and their roots extend below the treated layer. Diflufenican, the other option, is used to control wild radish, *Raphanus raphanistrum*, but has a limited weed spectrum.

Metribuzin, a triazinone, has been suggested as an alternative herbicide to use post-emergence on triazine tolerant cultivars. It has the advantages of higher water solubility and leaf uptake than simazine along with a broader weed control spectrum. Herbicide tolerance trials have confirmed that triazine tolerant cultivars also tolerate metribuzin. Variation in metribuzin tolerance of different crop cultivars has been shown in soybeans (5) and wheat (3).

In 1992 a series of field trials were conducted to determine the tolerance and efficacy of metribuzin alone, or in mixtures for post-emergence use on lupins. The target weed species were doublegee, *Emex australis*, wild radish, fumitory, *Fumaria muralis* and a variety of grasses (mainly *Lolium rigidus* and *Bromus* spp.) that had either been transplanted or had survived the IBS simazine application.

METHODS

In 1992 five replicated trials were conducted in commercially grown crops of Gungurru lupins in Western Australia (Table 1). Three sites had weeds surviving the IBS simazine applications at the rate recommended for each soil type, while two had low weed numbers and were used to determine crop tolerance. The trial design used was a randomised block design with 3 replications of plots 3x20 m. The area harvested in each plot was 1.4x20 m.

The herbicide treatments included a metribuzin response curve 50-210 g/ha, diflufenican 75 g/ha, simazine top-ups 500 and 1100 g/ha, and combinations of metribuzin with crop oil, simazine, grass selective herbicides and diflufenican (Table 2). Assessments included visual ratings, weed and lupin plant counts and grain yields.

The yield data was analysed by a nearest neighbour technique (Spatial Analysis of Field Experiments (2)) prior to analysis of variance.

Table 1. Description of 1992 trial sites.

Site	Soil type	BS simazine kg/ha	Dominant weeds	Crop stage sprayed
Wongan Hills	yellow clay sand Uc5.22	1.6	nil	6-8 leaf
Yelbeni	sandy duplex Dy4.82	1.1	nil	3 leaf
Yorkrakine	loamy sand Dy4.83	1.1	doublegee, radish, bromegrass	3-5 leaf
Yealering	loamy sand, poorly drained Dy5.41	1.1	doublegee, radish, ryegrass	6-10 leaf
Mt Barker	loamy duplex Dg1.41	1.1	fumitory, ryegrass	3 leaf

RESULTS AND DISCUSSION

Tolerance. Soon after application of metribuzin there was marked leaf yellowing and leaf tip burning, and at the highest rates there was also leaf drop. The crop growth was retarded by about one week but within 2 to 3 weeks there were no colour differences between treatments. Plots treated with greater than 140 g/ha of metribuzin, or with crop oil additives, were slightly shorter and bushier than untreated plots.

Gungurru lupins tolerated the highest rate of metribuzin tested at all sites without any loss of grain yield (Table 2). The required rate is between 70-100 g/ha depending on target weeds. The resulting yields were similar to those from simazine at each site. Mixtures with diflufenican, grass selectives and simazine were all tolerated in these trials.

The addition of spray oils to metribuzin could not be recommended at the 105 g/ha rate as this treatment showed the greatest visual damage after spraying. This did not translate into significant yield reductions but would cause concern to growers. The possibility of reducing metribuzin rates by the addition of oil has not been investigated. The severity of brown leaf spot (*Pleiochaeta*) was not increased by application of metribuzin at Yorkrakine, the one site infected, though the addition of oil or diflufenican increased the severity of infection.

Yields at both Mt Barker (weedy) and Wongan Hills (weed-free) were increased significantly by herbicide application (Table 2). The yield increase at Mt Barker was problably due to removal of competition from fumitory. The increase in yields at Wongan Hills may have been caused by stress inducing increased pod set or the reduced leaf area in early winter which conserved soil water for use in late spring. The untreated plots were vegetative but didn't set many pods.

Table 2. Yields of Gungurru lupins treated with metribuzin or alternative herbicides at five sites in 1992 expressed as percent untreated.

Post-emergence treatment	Rate g a.i./ha	Wongan Hills	Yelbeni	Yorkrakine	Mt Barker	Yealering
untreated (kg/ha)		1438	948	981	1270	1274
diflufenican	75	106	109	98	109	95
simazine	500	106	108	105	135	95
simazine	1100	108	97	112	135	115
metribuzin	52	113	115	108	118	
metribuzin	70	118	100	109	133	103
metribuzin	105	110	99	106	122	94
metribuzin	210	116	98	99	139	
metribuzin + oil (Ulvapron)	105 + 1%	109	99	92	143	109
metribuzin + simazine	70 + 500	110	100	115	159	99
metribuzin + diflufenican	105 + 50	113	106	104	137	92
metribuzin + sethoxydim	105 + 50	112*	108*	101	141	117
l.s.d. P=0.05		11	ns	15	22	18

* 100g/ha sethoxydim applied at Yelbeni and Wongan Hills

In lupins only 40% of final biomass is produced prior to flowering so flowers compete with lateral branch growth for assimilates. Bulky impressive crops tend to produce disappointing yields and it has been suggested that an environmental stress is needed to increase the number of pods set rather than to produce leafy plants. Metribuzin has been suggested as a growth regulator in lupins to cause stress and increase pod set. However trials where metribuzin has been applied at flowering have not reliably increased yields (Seymour, pers. comm.).

Efficacy. Metribuzin gave good control of doublegees. The rate required for control of small doublegee (3-4 leaf) was 70 g/ha (Table 3) but for larger plants (>5-6 leaf) 100 g/ha was needed (not shown). Low rates of metribuzin (<50 g) did not kill all small doublegee plants but allowed lupins to suppress weeds by shading. The doublegee were prevented from vining through the lupin canopy so avoiding contamination at harvest and reducing seed set. Low densities of doublegee cause yield losses by vining through the canopy and expand to occupy any available space. Small wild radish plants (3-4 leaf) were controlled by 70 g/ha, the same rate as used for doublegee.

In several small ancillary trials, mixtures of metribuzin and simazine, or metribuzin and diflufenican gave the best control of large, transplanted doublegee. In farmer use, the best control of large wild radish plants (up to 1 m in diameter and height) came from a mixture of 105 g/ha metribuzin plus 50 g/ha diflufenican which controlled all plants (Bowran unpublished data). There is no other herbicide option for this size plant.

There appeared to be synergism between mixtures of metribuzin and diflufenican at low application rates. It is possibile that diflufenican, or surfactants in the formulation, are enhancing leaf uptake of metribuzin. Using spray oils could also have this effect as it increased the activity of metribuzin as shown by increased leaf damage in lupins. The addition of crop oils to atrazine significantly increases leaf uptake (4). Leaf uptake is most important with large, established weeds as their deep taproots enable them to escape herbicides applied to the soil surface.

Table 3. Weeds present (plants/m^2) at two sites treated with metribuzin or alternative herbicides. Counts taken six weeks after application

Post-emergent treatment weed stage at application	Rate g a.i./ha	Yorkrakine		Mt Barker	
		doublegee (3-4 leaf)	bromegrass (2 leaf)	fumitory (2 leaf)	ryegrass (2 leaf)
untreated (kg/ha)		9.6	28.9	34.8	60.0
diflufenican	75	5.4	17.9	1.8	51.6
simazine	500	4.7	21.1	0	8.6
simazine	1100	2.1	11.4	0	2.4
metribuzin	52	3.6	23.6	0	46.8
metribuzin	70	2.1	8.6	0	43.8
metribuzin	105	2.6	22.3	0	19.2
metribuzin	210	0.5	12.9	0	15.0
metribuzin + oil (Ulvapron)	105 + 1%	1.5	23.6	0	17.4
metribuzin + simazine	70 + 500	0.5	11.8	0	4.8
metribuzin + diflufenican	105 + 50	1.1	31.5	0	18.0
metribuzin + sethoxydim	105 + 50	5.4	24.3	0	2.0
l.s.d. P=0.05		3.9	17.4	2.3	9.8

Fumitory was controlled by 50 g/ha metribuzin but 0.5 kg/ha simazine gave an equal result (Table 3). At an adjacent trial, fumitory was also removed by either simazine or metribuzin (Gilbey pers. comm.). Economics dictate that simazine would be the better option for fumitory control in moist soil conditions.

Grass control with metribuzin was unreliable. At Mt Barker the better results came from the simazine options (Table 3). Simazine at 1.1 kg/ha controlled 96% of ryegrass, equal to sethoxydim. 105 g/ha of metribuzin gave control of 68% of ryegrass plants but there was little benefit from doubling the rate to 210 g/ha (75% control). This is less than a grass selective herbicide would achieve if there was no herbicide resistance. However, at a herbicide resistant ryegrass site where metribuzin was used as an alternative grass selective herbicide in lupins, control was equal to carbetamex but at lower cost (Gill, pers. comm.). Control of bromegrass in wheat with metribuzin has been unreliable post-emergence, and more effective if applications are followed by rain (3). The Yorkrakine site was dry for two weeks after application and numbers variable across the site so control was erratic.

Using two related chemicals, simazine and metribuzin, in the same lupin crop has implications for herbicide resistance development. Annual ryegrass has not developed resistance to simazine under current lupin cropping rotations, probably due to a limited kill of 60-80% of ryegrass plants. Because metribuzin has the same site of action as simazine their combined use will increase selection pressure for resistance in ryegrass. If metribuzin is used as an alternative to grass selective herbicides ('fops' and 'dims') then these may be saved for less frequent use in other parts of the rotation. The target weed species were not grasses in most situations and grass control was a bonus to controlling broad-leaf weeds.

To conclude, metribuzin was a viable option to control broad-leaved weeds in lupin crops and may have advantages in dry soil conditions or when the target broad-leaved weeds are large. The tolerance of Gungurru to triazines allowed good selectivity at weed control rates.

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HERBICIDE TOLERANCE OF POTENTIAL ORCHARD GROUND COVERS

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Summary. This paper presents initial results from a study to minimize herbicide use in orchards by growing ground cover species. The philosophy of growing ground cover species which tolerate herbicides under orchard trees is discussed, and results of herbicide tolerance studies for some potential ground cover species are presented. Three prostrate perennial species, ajuga (*Ajuga reptans*), pearlwort (*Sagina procumbens*) and pratia (*Pratia pedunculata*) have been treated with a wide range of herbicides suitable for use in orchards. Ajuga and pearlwort tolerated enough of the herbicides to make establishment and maintenance of pure swards of these species under orchard trees feasible.

INTRODUCTION

Competition from vegetation growing under fruit trees is usually minimised by removing all vegetation near the base of trees with herbicides, and by regularly mowing vegetation between the rows of trees. The lack of ground cover in the sprayed areas is very conducive to germination of weed seeds, so residual herbicides are generally applied to prevent rapid reinvasion by weeds. Regular applications of foliar herbicides are usually also required to remove weeds resistant to the residual herbicides or which colonise the bare ground when the residual herbicides lose effectiveness (2). Thus several types of herbicide are present under trees as fruit is developing.

With the increasing public pressure to reduce the use of pesticides for food production, some growers are interested in developing alternative strategies for reducing competition under fruit trees. One possibility would be to establish low-growing non-competitive ground cover species under trees. Such species would need to be dense enough to prevent weed seeds from germinating yet not compete with trees for nutrients or water, and not require mowing. Ground cover species have been used for many years in amenity horticulture (5). However they generally require considerable labour during the establishment phase to remove weed species which germinate before a dense canopy has formed. In orchards, research into possible ground cover species has concentrated mainly on small grass species (1) and also various legumes such as clovers (3).

However there is a wide range of other perennial species which could potentially act as ground cover in orchards and which may be less competitive than grasses or legumes, allowing them to be planted right to the base of trees. Such species are often considered as weeds. The main problem with growing such species is that more competitive weed species usually invade such swards during their establishment (4). Thus selective herbicides are needed to remove unwanted plant species from ground cover swards. If the objective of growing ground covers in orchards is to minimise the use of herbicides during the growing season, such herbicides could be used while trees are immature to aid establishing swards, and during crop dormancy to maintain pure swards.

This paper describes initial experiments at Massey University to test the herbicide tolerance of potential ground cover species. Ajuga and pratia were chosen as species already used as ground covers in amenity horticulture, while pearlwort is a mat-forming weed species tolerant of several herbicides used in nurseries.

METHODS

Experiment 1. Individual plants of ajuga, pratia and pearlwort were established in polythene bags containing a 60:40 mixture of peat and pumice. A slow release fertiliser was added and the plants were established from transplants taken from the field. They were kept in a heated glasshouse which remained between 16 and 22°C for the duration of the trial. Bags were placed on felt mats which were automatically moistened twice daily.

Once plants were well established in each bag, herbicide treatments were applied on 12 June 1992. Herbicide treatments are listed in Table 1. Each treatment was applied to five ajuga, five pearlwort and four pratia plants, and treatments were allocated using a completely randomised design for the first two species and a randomised complete block design for the pratia. Herbicides were applied in 243 l/ha of water using a laboratory pendulum sprayer similar to that described by Wiese (6).

The tolerance of plants to the herbicides were visually assessed using a scoring technique on nine occasions over the subsequent 14 weeks. An analysis of variance was performed on the arcsine transformed scores, and means were separated using the Student-Newman-Keuls multiple range test.

Experiment 2. Based on results from Experiment 1 and unpublished field trials, a second glasshouse experiment tested the tolerance of ajuga and pearlwort to further herbicide treatments. Plants were established in polythene bags containing a Kiwitea loam soil with a pH of 5.0 and 7.7% organic matter. The plants were grown in a glasshouse and watered as for Experiment 1, though the temperature for this experiment was between 18 and 26°C. Treatments were replicated five times using a completely randomised design for each species and applied on 28 January 1993 using the same sprayer as in Experiment 1 with a water rate of 320 l/ha. Plants were scored three times and analyzed as above.

RESULTS AND DISCUSSION

Pratia did not tolerate enough herbicides to be worth studying further after the initial screening trial. It was also found to die back with frosts in winter, allowing winter-germinating weeds to establish. However ajuga and pearlwort appear more promising. Oxadiazon, simazine and pendimethalin are all residual herbicides that can be used to assist with the establishment of ajuga. It forms a dense canopy once it has established, and its tolerance of haloxyfop, paraquat, diquat, clopyralid and asulam will allow many weed species which do establish to be removed at a time of the year when fruit trees are dormant. The paraquat and diquat do cause some initial knock-back of the plants, but they soon recover. The strong tolerance of pearlwort to residual herbicides such as oxadiazon, pendimethalin, oxyfluorfen and dichlobenil should allow a sward of this species to be successfully established. Haloxyfop, clopyralid, asulam, dalapon, 2,4-DB, MCPB and low rates of 2,4-D should allow most weeds which do establish to be successfully removed. However field trials are now required to determine whether this small plant can form a dense enough canopy to prevent weeds from establishing during the growing season when herbicides are not assisting it.

Table 1. The effects of herbicides applied at post-emergence on the health of three potential ground cover species as assessed by a scoring technique (1 = unaffected, 10 = dead) at 7 and 14 weeks after application. Means within a column sharing the same letter are not significantly different (p = 0.05).

Herbicide	Appln. Rate kg ai/ha	Ajuga		Pearlwort		Pratia	
		7 wk	14 wk	7 wk	14 wk	7 wk	14 wk
amitrole	3.2	4.4 cd	7.4 ab	9.0 bcd	9.6 ab	7.4 cd	9.9 a
asulam (sodium salt)	1.2	2.1 de	1.0 c	1.0 e	1.0 c	1.7 e	2.1 b
atrazine	1.0	7.9 b	9.3 a	10.0 a	10.0 a	10.0 a	10.0 a
clopyralid (amine salt)	0.3	1.3 e	1.0 c	1.0 e	1.0 c	6.0 d	8.3 a
2,4-D (amine salt)	1.2	7.1 b	10.0 a	8.6 cd	8.9 ab	2.4 e	7.9 a
dichlorprop (potassium salt)	2.5	7.3 b	10.0 a	9.8 ab	9.4 ab	7.5 cd	8.9 a
diquat (dibromide salt)	0.6	9.8 a	4.7 bc	10.0 a	7.8 b	10.0 a	10.0 a
glufosinate (ammonium salt)	1.0	10.0 a	10.0 a	10.0 a	9.4 ab	10.0 a	10.0 a
glyphosate (isopropylamine salt)	0.36	6.1 bc	9.8 a	10.0 a	8.5 ab	8.2 c	9.1 a
haloxyfop (ethoxyethyl ester)	0.25	1.0 e	1.0 c	1.0 e	1.0 c	1.2 e	1.0 b
ioxynil (octanoyl ester)	0.67	7.7 b	4.3 bc	9.6 abc	8.9 ab	9.7 ab	6.9 a
linuron + diuron	1.7 + 1.1	6.4 bc	4.5 bc	10.0 a	10.0 a	10.0 a	10.0 a
MCPA (potassium salt)	1.1	7.6 b	10.0 a	9.6 abc	9.2 ab	8.8 bc	8.3 a
oxadiazon	1.6	2.5 de	1.4 c	1.0 e	1.0 c	2.2 e	1.2 b
paraquat (dichloride salt)	0.4	7.4 b	1.2 c	9.6 abc	2.9 c	9.6 ab	9.1 a
pendimethalin	1.3	1.7 e	1.0 c	1.6 e	1.2 c	1.6 e	2.2 b
propanil + carbaryl	4.2 + 0.67	8.4 b	3.2 bc	10.0 a	10.0 a	10.0 a	10.0 a
tribenuron	0.011	2.3 de	5.2 bc	8.4 d	10.0 a	2.7 e	7.4 a
untreated	-	1.5 e	1.5 c	1.2 e	1.2 c	1.0 e	1.0 b

A number of other low-growing perennial species are being assessed for their tolerance of herbicides at present. Emphasis is being placed on herbicides registered for use in fruit crops. The most promising species will be planted out into an orchard to observe how well they prevent weeds from establishing, tolerate orchard traffic, shade and drought, and whether weeds which do establish can be successfully removed during winter with herbicides.

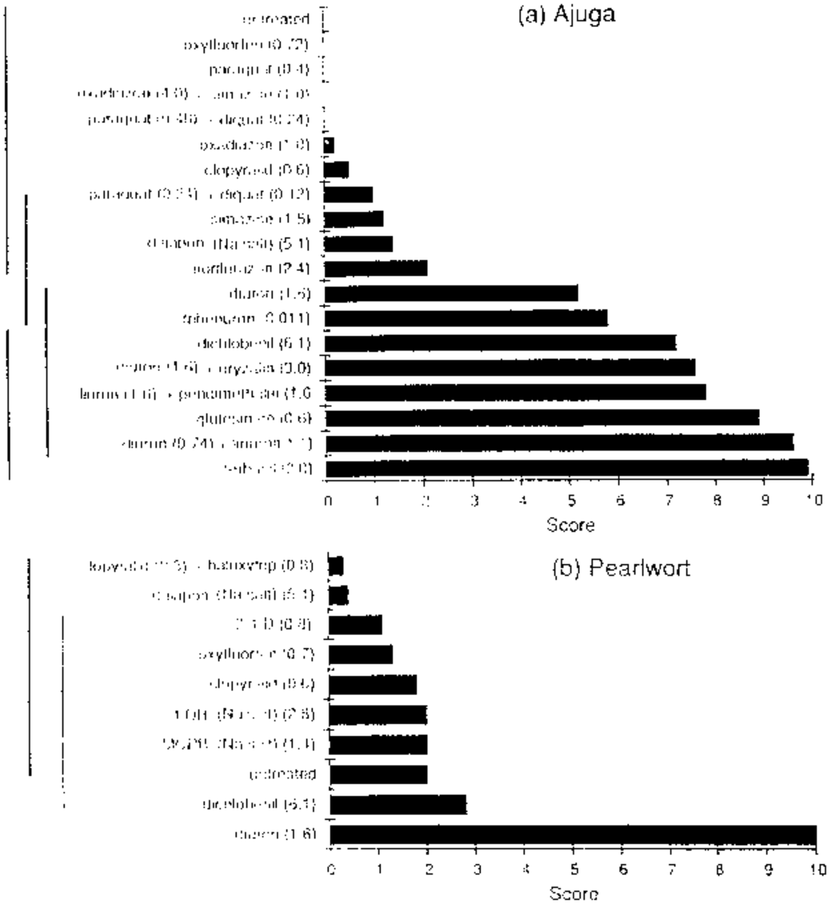

Figure 1. The tolerance of ajuga and pearlwort to post-emergence herbicide treatments as assessed by a scoring technique (0 = unaffected, 10 = dead) at 7 weeks after application. Treatments joined by the vertical lines on the left are not significantly different (p = 0.05). Formulations are as in Table 1 except where shown otherwise. The oxadiazon + simazine and dichlobenil treatments were applied as granules.

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WEED INTERFERENCE IN TEA TREE PLANTATIONS

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Summary. Tea tree, *Melaleuca alternifolia*, is an annually-coppiced tree grown on the north coast of New South Wales for its leaf essential oil. In field experiments tea tree biomass yield did not always decline in the presence of weeds. This suggested that weed interference in the tea tree regrowth cycle is intermittent, and is dependent on interactions between the tea tree growth rate, harvest date, weed species present and soil moisture availability.

INTRODUCTION

The leaves of tea tree, *Melaleuca alternifolia*, contain an essential oil which is used as an antifungal agent, disinfectant or perfume. Tea tree occurs naturally in seasonally-waterlogged soils on the mid-eastern coast of Australia. Plantations have been established in the past 15 years for tea tree oil production. Trees are annually harvested to near-ground level, cut stumps then coppicing to commence a new shoot regrowth cycle.

In a 1992 survey approximately 80% of tea tree growers considered weeds to be a major limit to production, with a mean estimated regrowth biomass loss of approximately 45% if weeds are not controlled (Virtue and McMillan, unpublished data). Corresponding data on weed interference in other coppice systems to verify this estimate are negligible. It is difficult to compare coppicing tea tree with other tree crops due to the annual dramatic increase in the root:shoot ratio at harvest. This sudden change may impede root growth (2, 3) and make tea tree vulnerable to root competition from weeds. Shoot harvest to near-ground level may encourage weed interference, removing shade to promote weed germination and growth, and locating new tea tree shoot regrowth where it may have to compete with weeds for light. Alternatively tea tree may tolerate weed presence as coppicing trees can exhibit extremely vigorous early shoot growth (1).

This paper aims to quantify the effect of weed interference on tea tree biomass yield throughout the regrowth cycle.

METHODS

Sites. Experiments were conducted at three sites; Lismore, Ballina and Grafton. The Lismore site was a commercial plantation with trees in 4-row hedges (trees spaced 0.3x0.3 m) on raised beds 1.0 m apart. The Ballina site was a research plot with trees in single rows (trees spaced 0.25 m or 0.50 m within rows x 1.3 m between rows). The Grafton site was a commercial plantation with trees in 2-row hedges (trees spaced 0.30 m within rows x 0.50 between rows) on raised beds 0.80 m apart. All sites were on alluvial clay soils. Harvest dates were 6 February 1992 at Lismore, 5 February 1992 at Ballina and 16 April 1992 at Grafton.

Treatments and experimental design. All three sites had two basic treatments; no weeds present (NW) and weeds present (W). In the NW treatment weeds were mainly removed by hand-hoeing. In the W treatment weeds were allowed to grow unchecked throughout the experiment. Each treatment plot consisted of 20 trees for a certain sampling date. Sampling dates were 8, 15 and 57 weeks from harvest at Ballina, 13, 30 and 54 weeks from harvest at Grafton, and 8, 13, 19 and 50 weeks from harvest at Lismore. All experiments were randomised complete block designs with 3 replications at Ballina and 4 replications at Lismore and Grafton.

Sampling and measurement. At each sampling date the post-harvest coppice growth of 20 trees per plot was cut and bulked. Total shoot biomass was calculated from the product of the dry weight:fresh weight (DW:FW) ratio and the total FW. Leaf biomass was calculated from the product of the DW proportion of leaf and the total DW shoot biomass. Biomass yields (per 20 plants) were converted to yield/m^2 to enable comparisons between sites with different planting configurations, and to reduce the potential bias of different plot sizes due to missing trees. Weed samples were taken at each sampling date to measure weed shoot biomass/m^2. Five 0.1 m^2 strips of live weed shoot material were randomly taken, perpendicular to tree rows, and bulked.

Statistical analysis. Yield data were standardised via loge transformations, and analysed using ANOVA and 5%LSD. A sawfly (*Ptergophorous* sp.) larvae infestation at Ballina in April-May 1992 caused varying degrees of defoliation of many trees prior to the second sampling date. The raw leaf biomass data at the second sampling date were converted to a full leaf figure using a regression equation between DW leaf proportion and defoliation score. At the third sampling date regression analysis gave no strong relationship between individual plant FW and its former defoliation score, and thus the yield data was not adjusted.

RESULTS AND DISCUSSION

Yield data for Lismore are presented in Fig. 1. Total shoot biomass yields were only significantly reduced ($P<0.05$) in the W treatment at 13 and 19 weeks from harvest, by 32% and 34% respectively (relative to the NW treatment). Similarly leaf biomass yields were significantly reduced at these sampling dates; 32% at 13 weeks ($P<0.07$) and 33% at 19 weeks ($P<0.08$). Dominant weed species were cobbler's pegs, *Bidens pilosa*, tall fleabane, *Conyza albida*, nutgrasses, *Cyperus* spp., wandering Jew, *Commelina* spp., stagger weed, *Stachys arvensis*, and verbena, *Verbena* spp.

Yield data for Ballina are presented in Fig. 2. No significant differences in tea tree total shoot biomass or leaf biomass between the W and NW treatments were detected ($P<0.05$) at any sampling date. High variation inflated the limit of detection, this limit being a 60% total shoot biomass yield reduction (relative to the NW treatment) at 57 weeks. The weed flora was dominated by perennial grasses including setaria, *Setaria sphacelata*, paspalum, *Paspalum* spp., couch, *Cynodon dactylon*, and carpet grass, *Axonopus* spp.

Yield data for Grafton are presented in Fig. 3. Total shoot biomass yields were significantly reduced in the W treatment (relative to the NW treatment) by 28% at 13 weeks ($P<0.07$) and by 37% at 54 weeks from harvest ($P<0.05$). Leaf biomass yields were similarly significantly reduced ($P<0.05$) by 33% at both 13 and 54 weeks from harvest. Dominant weeds were spear thistle, *Cirsium vulgare*, pennywort, *Centella asiatica*, slender celery, *Apium leptophyllum*, common rush, *Juncus usitatus*, and grasses (summer grass, *Digitaria* spp., couch, paspalum and carpet grass).

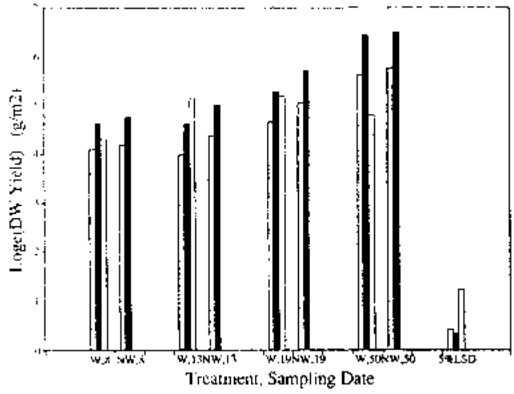

Figure 1. Lismore tea tree leaf biomass (grey bars), tea tree total shoot biomass (solid bars) and weed shoot biomass (empty bars) for the weeds present (W) and no weeds (NW) treatments at each sampling date.

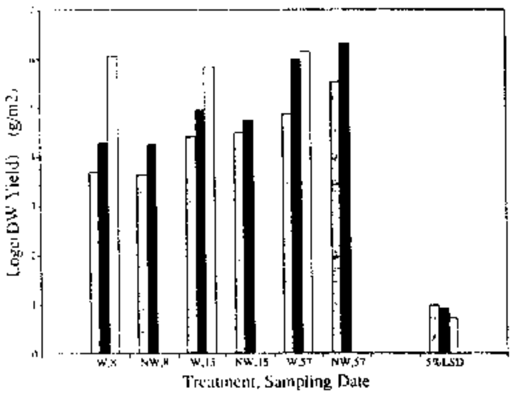

Figure 2. Ballina tea tree leaf biomass (grey bars), tea tree total shoot biomass (solid bars) and weed shoot biomass (empty bars) for the weeds present (W) and no weeds (NW) treatments at each sampling date.

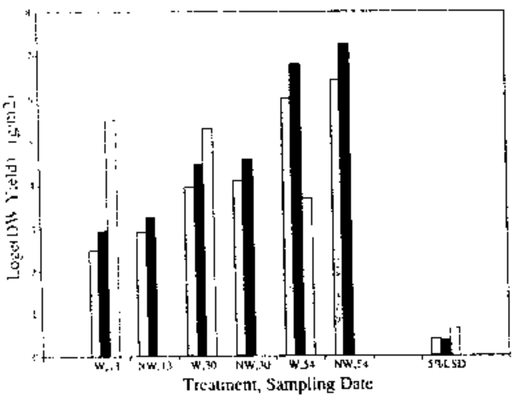

Figure 3. Grafton tea tree leaf biomass (grey bars), tea tree total shoot biomass (solid bars) and weed shoot biomass (empty bars) for the weeds present (W) and no weeds (NW) treatments at each sampling date.

The results show that weed interference can reduce biomass yields in tea tree, but such yield losses are intermittent and difficult to detect. Genetic variation (tea tree seed is collected from natural stands) was probably a major contributor to the detection problem. The extent of weed interference in tea tree plantations seems dependent on interactions between such factors as the tea tree growth rate, the harvest date, soil moisture availability and weed species present. Relative growth rates (data not given) to the first sampling dates at Lismore and Ballina were high (suggesting coppice vigour (1)), and trees grew well regardless of weed presence. Conversely at Grafton a late harvest date (with consequent lower temperatures) gave a slow growth rate to the first sample date, and may have made the trees susceptible to light competition from weeds. Light competition from weed species such as cobbler's pegs, wandering Jew and stagger weed may have reduced biomass yields at Lismore at the 13 and 19 week sampling dates. Soil moisture was readily available during the early regrowth at all three sites, and with probably high root:shoot ratios the tea tree would have obtained sufficient water and nutrients to not compete with weed root uptake. Root competition may have become more important as the trees grew larger, as at Grafton in late spring when a period of adequate soil moisture gave vigorous tree and weed growth. At Lismore during spring-summer and at Grafton during early spring soil moisture may have been so limiting that weed growth was poor and the W and NW treatment yields converged.

The only significant ($P<0.05$) final yield loss was 33% (in leaf biomass) at Grafton. This equates to a loss of $1176/ha (based on a measured oil concentration of 0.014 mL oil/g DW leaf, oil density of 0.89 g/mL and oil purchase price of $45/kg). At lismore and Ballina only large yield differences could be detected as statistically significant, but economically significant losses could still have occurred. If the observed differences in final mean yields between the W and NW treatments were infact losses due to weed interference, then these equated to $366/ha at Lismore (measured oil concentration 0.056 mL oil/g DW leaf). These figures certainly suggest that low cost weed control is profitable.

ACKNOWLEDGMENTS

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SELECTIVE CONTROL OF WANDERING JEW WITH FLUROXYPYR FOLIAR SPRAY

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Summary. Allergic contact dermatitis in a dog was caused by wandering jew, a widespread weed in gardens and wet shaded areas of coastal New South Wales. This prompted experimenting with fluroxypyr, as the methyl heptyl ester, on the weed. Fluroxypyr at 6 g acid equivalent/L of water resulted in complete brownout and residual stolon kill of wandering jew. Rates of 2 or 3 g/L fluroxypyr were almost as effective but there was a low level of regrowth. Lower rates were marginal. Fluroxypyr was selective to grasses and many ornamental plants, and proved to be an effective herbicide on wandering jew which had been difficult to control with other herbicides and hand-weeding was laborious and expensive.

INTRODUCTION

Wandering jew, *Tradescantia albiflora* Kunth, (*T. fluminensis* auct. non Vell in North America) is a succulent creeping perennial herb which is widespread in moist shady situations especially along streams and gullies. This plant has caused high incidence of allergic contact dermatitis in the dog (1), and has been associated with nitrate poisoning of cattle (2). Allergic contact dermatitis in the author's boxer dog at Pennant Hills, New South Wales, in 1980 was caused by wandering jew. It became necessary to remove the weed and a herbicide spray as an alternative to laborious hand-weeding was sought. Fluroxypyr as the methyl heptyl ester had been effective on a wide range of broadleaf weeds in turf and garden areas and was used as a foliage spray in experiments to control wandering jew.

METHODS

The efficacy of fluroxypyr on wandering jew was evaluated in 11 experiments between January 1980 and February 1993. Experiments included eight unreplicated trials with one or two concentrations and three dose response trials with 3-6 concentrations in a randomised complete block design with three replicates. A pneumatic knapsack sprayer with adjustable 1 mm cone nozzle was used to thoroughly wet leaves and stolons. Spray volume varied with weed density, from 3000 L/ha (100% ground cover) to 1600 L/ha (60% ground cover). No adjuvants were used. Plot size ranged from 1x2 m to 3x3 m. Wandering jew was 8-30 cm tall at application and the fresh weight at the time of early summer treatments in 1992 was 40 tonnes/ha. Trials covered wandering jew growing in various levels of shade. Treatment details are given in Table 1.

Table 1. Outline of experiments on wandering jew

Expt.	Spray date	Growth stage[a]	Fluroxypyr (g/L)[b]	Plot size (m)	Reps	Last rating (daa)[c]	Respray mulch[d]
1	27.01.80	post	6	2 x 2	1	152	m
2	15.06.85	pre	3	2 x 3	1	183	m
3	19.09.89	pre	1.5,3	2 x 2	1	153	m
4	28.07.90	pre	1.5,3	1 x 3	1	152	m
5	25.08.90	pre	1.5,3	2 x 3	1	125	m
6	17.01.91	post	2,3	3 x 3	1	159	m
7	20.07.92	pre	2,3	2 x 2	1	179	m
8	12.08.92	pre	0.5,1,1.5, 2,3	1 x 2	3	152	r
9	05.10.92	flow	1.5,3,6	1 x 2	3	96	r
10	10.12.92	flow	0.5,1,1.5,2,3,6	1 x 2	3	80	r

[a] pre, pre-flowering; post, post-flowering; flow, flowering.
[b] Acid equivalent/L water
[c] Days after application
[d] m, mulched with grass clippings; r, resprayed with 3 g/L fluroxypyr.
Experiments were visually rated for % leaf brownout, % necrosis of the whole plant (leaves + stolons) and % regrowth suppression.

RESULTS AND DISCUSSION

Fluroxypyr 6 g acid equivalent/L of water was the only rate used in the first experiment and gave complete necrosis of leaves and stolons of wandering jew 80 days after application (daa) and there was no regrowth 5 months after application. Subsequent results between 1985-1991 indicated fluroxypyr 3 g/L was almost as effective and superior to 1.5 g and 2 g/L.

Dose response results from treatment of dense pre-flowering, flowering and post-flowering wandering jew during winter, spring and summer seasons in 1992 indicated that single sprays of fluroxypyr at 2 g or 3 g/L was required for leaf and stolon desiccation and a high level or regrowth suppression. Fluroxypyr at 0.5 g and 1 g/L gave leaf brownout but inadequate stolon kill and 1.5 g/L gave variable stolon kill and too much regrowth occurred. Figures 1 and 2 show results from two replicated dose response experiments and a clear dose response was evident.

Leaf brownout and leaf plus stolon necrosis and the level of regrowth suppression increased with increasing concentrations of fluroxypyr in the spray. The effect on winter growth was slower than for spring and summer. The overall effect from the experiments is shown in Table 2.

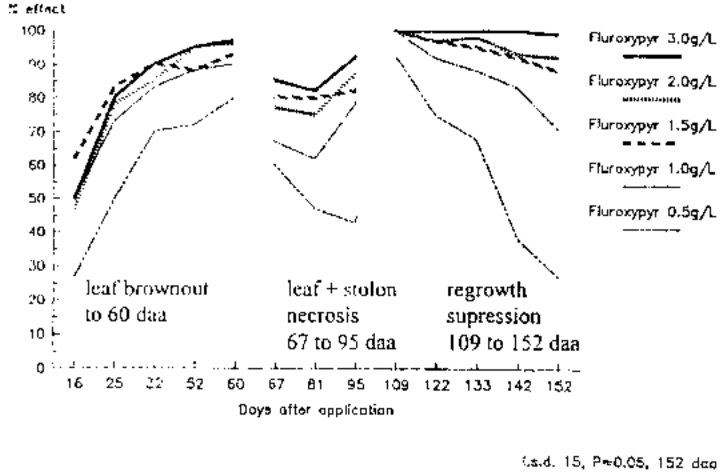

Figure 1. Effect of foliage spraying fluroxypyr on pre-flowering wandering jew, August 1992.

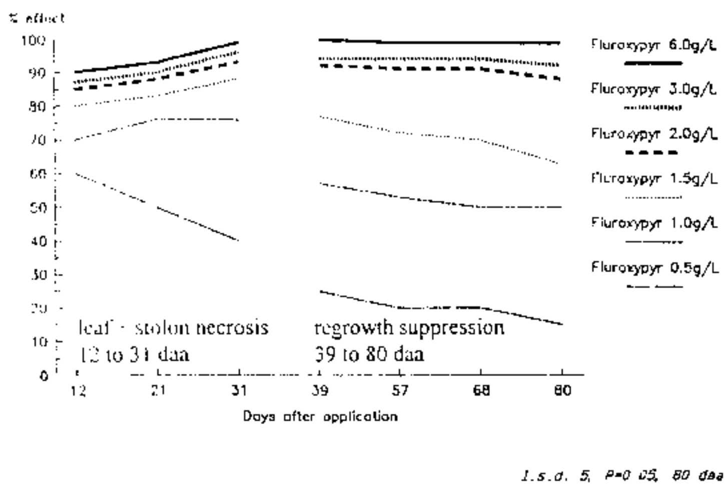

Figure 2. Effect of foliage spraying fluroxypyr on late-flowering wandering jew, December 1992.

Fluroxypyr 6 g/L gave the best control of wandering jew. Fluroxypyr at 3 g/L applied as a thorough wetting foliage spray gave a mean of 96% regrowth suppression over nine experiments (standard deviation +/- 3%). The mean duration for regrowth suppression with this rate was 142 daa (s.d. +/- 18). Timing did not appear critical when soil moisture was considered adequate except for experiment 10 (Fig 2) where there was 8% regrowth 80 daa (1% with 6 g/L and 12% with 2 g/L fluroxypyr), which was possibly due to high rainfall following spraying and that maximum leaf and stolon necrosis only reached 94% at 39 daa compared to the mean maximum leaf and stolon necrosis of 98% at 95 daa.

Table 2. Overall effects of spray concentrations of fluroxypyr on wandering jew

Fluroxypyr[a]	No. expts	Max. leaf b'out %	Daa	Max. leaf+stolon Necrosis %	Daa	Regrowth	Suppression % Mean	Daa
6	3	100	21-49	99-100	39-100	99-100	99.3	80-152
3	9	100	21-63	94-100	39-129	92-100	96.1	80-183
2	4	98-100	31-63	92-98	39-142	88-97	93.2	80-179
1.5	6	95-100	31-60	75-93	39-109	63-88	81.0	80-153
1	2	85-96	31-60	54-85	39-109	50-71	60.5	80-152
0.5	2	75-85	31-60	25-68	39-109	15-27	21.0	80-152

[a] Fluroxypyr, g/L of water

As well as proving to be effective on wandering jew and less laborious and expensive than hand-weeding, 3 g/L fluroxypyr was selective to grasses and many ornamental plants when stem and foliage contact was kept to a minimum. Fluroxypyr 3 g/L is the preferred rate based on cost-efficacy and better selectivity to non-target broadleaf plants than the higher rate of 6 g/L.

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CONTAINER-GROWN TEMPERATE NURSERY STOCK: HERBICIDE SCREENING AND WEED CONTROL

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Summary. Thirteen herbicide treatments were applied to 50 plant species or cultivars in weed free containers. Growth and quality of treated plants were compared to those from hand weeded controls. Overall, damage to nursery stock from the herbicides was very limited and manifested principally as a reduction in growth rather than as an effect on plant quality. The most damaging treatments were those containing oxyfluorfen. No herbicide treatment was totally safe to all species. The most sensitive species was *Hydrangea macrophylla*. The effectiveness of the herbicides was generally poor. Overall, effective long-term weed control without significant plant damage was provided only by oxadiazon.

INTRODUCTION

Weeds in container nursery stock reduce plant growth through competition, adversely affect plant quality and saleability and increase the spread of weeds to new sites. The high moisture and soil fertility conditions maintained in containers lead to rapid weed growth.

Weed control options in containers are limited. Cultivation is not feasible and hand weeding and mulching are the only practicable alternatives to herbicide application. Hand weeding is expensive, estimated at up to 30 times the cost of herbicide application (1) and costed in Australia at over $10,000 per hectare in 1985 (6). Mulching has not been investigated extensively but limited research suggests that it is expensive to implement and of poor effectiveness (3, Harradine, pers. obs.).

Research has led to the development of herbicide recommendations for weed control in container-grown plants (e.g. 2, 5, 6, 7) and the registration of several herbicides for this use in Australia. Problems have recently been encountered in the local nursery industry with the withdrawal of the widely used nursery herbicide chloroxuron and possible restrictions on the use of herbicides such as simazine and oryzalin following their restriction overseas. In addition, reliance on a single product or on a limited type of product may lead to the development of herbicide resistance in target weeds and is hence undesirable.

Ideal herbicide treatments for use in container-grown nursery stock will:

- be cost effective against the fairly specific range of weeds encountered,
- will have residual activity under the free draining and high moisture conditions of container growth,
- will not cause residue problems in nursery runoff or in nursery water recirculation systems,
- will be tolerated by the very large variety of species and cultivars grown by the Australian nursery industry, and
- have herbicide components with varying modes of activity to reduce the risk of development of herbicide resistance.

A three year research project was undertaken by the authors to develop herbicide recommendations based on these criteria. This paper reports the first of a series of experiments to screen nursery stock for tolerance to a range of potential herbicide treatments.

METHODS

The trial site was a commercial wholesale nursery at Seven Mile Beach near Hobart, Tasm!nia. Thirteen herbicide treatments wer% appl)ed to 50 ornamental plant species in 12 or 14 cm diameter pots (Table 1 and 2). There were six replicates per treatment.

The species were chosen to represent as wide a range as possible of plant types and species common to the temperate nursery industry. The species choice was restricted to those normally potted or repotted in late spring to early summer as it was proposed to test the herbicide tolerance of plants soon after potting into sterilised media. The potting mix was 90% composted pine bark and 10% sand.

Table 1. Plant species and cultivars used in the trial

No.	*Species*/Cultivar	No.	*Species*/Cultivar
1.	*Acacia howittii*	26.	*Hebe buxifolia*
2.	*Berberis darwinii*	27.	*Hebe* sp. La Seduisante
3.	*Betula alba*	28.	*Hydrangea macrophylla* Dwarf Red
4.	*Boronia heterophylla*	29.	*Ixodia achilleoides*
5.	*Brachyscome multifida*	30.	*Jasminum humile*
6.	*Callistemon* sp. Kings Park	31.	*Lavendula alba*
7.	*Calytrix tetragona*	32.	*Leptospermum juniperum* Horizontalis
8.	*Chrysanthemum frutescens*	33.	*Leptospermum nanum rubrum*
9.	*Chrysocoma coma-aurea*	34.	*Lippia citriodora*
10.	*Cistus candaniferens*	35.	*Melaleuca armillaris*
11.	*Clematis spooneri*	36.	*Potentilla* sp. Miss Wilmot
12.	*Coleonema* sp. Gold form	37.	*Prostanthera rotundifolia*
13.	*Convolvulus cneorum*	38.	*Pseudopanax* sp. Gold Splash
14.	*Correa decumbens*	39.	*Rhododendron hybrid* Red Wings
15.	*Cotoneaster horizontalis*	40.	Azalea
16.	*Crowea* sp. Festival	41.	*Rosa x.* Snow Carpet
17.	*Cytisus* sp. Snow Queen	42.	*Sagina subulata*
18.	*Dianthus alba*	43.	*Saxifraga* sp. Red Hedgehog
19.	*Dianthus caryophyllus* Knight Rose	44.	*Scaevola microphylla*
20.	*Dodonaea viscosa*	45.	*Serissa* sp. Snowleaves
21.	*Erica melanthera* Improved	46.	*Sollya heterophylla* White form
22.	*Erica* sp. Mrs Maxwell	47.	*Spiraea* sp. Snow Mound
23.	*Eucalyptus gunnii*	48.	*Thuja orientalis* Aurea nana
24.	*Grevillea curviloba*	49.	*Verbena tenera* Pink form
25.	*Hardenbergia violaceae*	50.	*Viburnum opulus* Sterile
			Westringia sp. Wynyabbie Gem

The normal sequence of commercial operations on the nursery resulted in species becoming available for spraying over a period of three weeks. They varied in age from one day to four weeks after potting at the time of herbicide application. Any weeds present in the pots were removed by hand prior to herbicide application.

Herbicides were applied on 6 and 20 December 1991 for 34 and 16 of the species respectively. The granular herbicide oxadiazon was weighed out and applied to the pots by hand. Other herbicides were applied by boom spray in 212 litres of water/ha through fan nozzles operating at 210 kpa. All herbicides were applied over the top of the plants and were washed off foliage with approximately 10 mm of overhead watering immediately after application.

On 23 April 1992, the herbicide application was repeated on 9 of the species. The other species were not retreated as the pot surface had been covered by plant foliage by this time.

After herbicide application, species 25, 28 and 39 were placed in a shade house (70% light transmission) and all other plants were placed in the open. Pots were randomised within the areas and maintained as for pots in the adjacent commercial nursery areas.

Notes on the effect of the herbicides were made at approximately fortnightly intervals. The effects of the herbicides were also quantitatively determined by measuring the height and width of the treated plants and scoring the parameters: "foliar damage", "flower quality", and "saleability". These data were compared with those for a fourteenth treatment: "hand weeded" (no herbicide application). All plants were measured over the period 30 March to 3 April 1992. Retreated plants were measured on 15 June 1992.

Plant growth data were analysed by analysis of variance for a species x herbicide factorial in a completely randomised design. After initial analysis, each species was analysed separately across the herbicide treatments. In this latter analysis, the means for each of the herbicide treatments were compared to that for the hand weeded treatment.

Weeds that established in the containers during the trials were identified, recorded and removed at approximately fortnightly intervals. Data are presented as cumulative weed numbers per pot for separate periods of the trial and analysed as a completely random design for herbicide treatments (across all species).

RESULTS AND DISCUSSION

Overall, damage to nursery stock from the herbicides was very limited and, in most instances, was manifested as a reduction in growth rather than as an effect on plant quality. The most damaging treatments were those containing oxyfluorfen and, to a lesser extent, the isoxaben + oryzalin mix. No herbicide treatment was totally safe to all species.

Widespread tolerance to oxadiazon granules and sensitivity to oxyfluorfen and isoxaben by nursery stock have been reported in other trials and from commercial experience (e.g. 2, 6, 7) although oxyfluorfen may be well tolerated when applied as a granular treatment (4, 5).

The most sensitive species overall was *Hydrangea macrophylla*, followed by *Brachycome multifida*, *Chrysocoma coma-aurea*, *Potentilla* "Miss Wilmot", *Jasminum humile* and *Grevillea curviloba*. Sixteen species (1, 7, 12, 18, 19, 20, 22, 25, 29, 31, 33, 41, 43, 46, 47 and 49) were tolerant of all herbicides tested. None of the most sensitive species from the first herbicide application was retreated. However, significant phytotoxicity was caused by several of the treatments to *Correa decumbens*, a species that was only slightly damaged by the initial application. Full details of the individual species responses (5 parameters for each of the 650 species-herbicide combinations) are available from the senior author.

Weed numbers were low during the first six weeks of the trial, demonstrating a lag phase while weed seeds spread into the pots from surrounding areas (Table 2). The main weeds were willow herb (*Epilobium* sp.), hairy bitter cress (*Cardamine hirsuta*), sowthistle (*Sonchus oleraceus*) and cudweed (*Gnaphalium* sp.).

The effectiveness of the herbicides was generally poor (Table 2). Cumulative weed number per pot was significantly lower than the hand weeded treatment for diphenamid, isoxaben, isoxaben + oryzalin, oryzalin + oxyfluorfen, oxadiazon and oxyfluorfen and for diphenamid, isoxaben, oryzalin + oxyfluorfen, oxadiazon and oxyfluorfen for the first and second six week periods of the trial respectively (Table 2). Treatments which significantly reduced weed number over the six week period after the second herbicide application were oryzalin + oxyfluorfen, oxadiazon and oxyfluorfen (Table 2).

Table 2. Mean cumulative number of weeds per pot for each of the 13 herbicide treatments and the hand weeded control six weeks and twelve weeks after the first herbicide application and six weeks after the second application.

Herbicide	Commercial product	Rate (kg ai/ha)	Six weeks[a]	Twelve weeks[a]	Six weeks[b]
chlorthal-dimethyl	Dacthal W750	8.25	0.66	6.52	5.69
diphenamid	Enide	5.50	0.25	3.03	4.43
isoxaben	Gallery	0.75	0.27	2.76	3.24
isoxaben +	Gallery +	0.45+	0.05	4.54	5.15
oryzalin	Surflan DF 850	1.70			
lenacil	Venzar	1.60	0.42	3.50	2.85
napropamide	Devrinol	2.25	0.38	5.11	4.02
norflurazon	Solicam	2.00	0.32	3.43	4.76
oryzalin	Surflan 850 DF	2.55	0.54	9.00	4.13
oryzalin +	Surflan DF 850 +	1.70+	0.02	3.17	1.02
oxyfluorfen	Goal	0.72			
oxadiazon	Ronstar Granules	4.00	0.04	1.17	0.52
oxyfluorfen	Goal	0.72	0.13	2.94	0.58
pendimethalin	Stomp 330E	0.99	0.48	5.37	7.13
simazine	Flowable Gesatop	1.10	0.31	4.73	7.83
handweeded			0.55	6.37	5.03
l.s.d. (P=0.05)			0.24	2.97	3.52

[a] Based on data for 300 pots for first herbicide application.
[b] Based on data for 54 pots for second herbicide application.

The effectiveness of oxadiazon and oxyfluorfen has previously been reported (1, 4, 5, 6, 7). However, the poor performance of oryzalin in this trial contrasts with its reported effectiveness for a similar weed spectrum (2).

Mean total weed number per pot for the twelve weeks after the first herbicide application was 6.9 for the hand weeded control and 1.2 for the most effective herbicide treatment (oxadiazon). While this indicates a highly significant decrease in weed number due to herbicide application, the actual weed number still represents a considerable weed problem in practice. In a small pot, even a single weed can compete strongly with the growing plant.

Overall, effective long term weed control without unacceptable plant damage to a large number of the species tested was achieved only with oxadiazon (Ronstar Granules™).

ACKNOWLEDGEMENTS

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CHOPPER IMAZAPYR HERBICIDE FOR WEED SUPPRESSION IN JAPAN A NEW CONCEPT FOR INDUSTRIAL VEGETATION

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Summary. Various weed management strategies are available in industrial vegetation control in Japan, where about 32,000 ha are treated by herbicides and 39,000 ha managed by manual weeding. Imazapyr (isopropyl ammonium=(RS)-2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl) nicotinate) as CHOPPER 1%AS has been developed for weed suppression in this area. Field trials have shown that foliar application of 50 to 100 g a.i./ha of product in a spray volume of 250 L/ha provided outstanding control of perennial weeds for 3 to 4 months.

INTRODUCTION

Imazapyr is already known as one of the imidazolinone class herbicides developed by American Cyanamid Company for industrial weed control, and for use in conifer forests and plantation crops.

The very unique activity of CHOPPER against the treated weeds was found early in the development of imazapyr, and it controls not only plant growth of perennial weeds, but also seed head development of perennial grasses.

Industrial vegetation management in Japan covered by herbicide treatment is about 32,000 ha and the management of manual weeding shows approximately 39,000 ha (Table 1). Therefore, a new concept of CHOPPER for industrial weed management was installed from 1983. This paper will present some of the field activities in Japan.

MATERIAL AND METHOD

Field trials. CHOPPER 1%AS at 50-100 g a.i./ha in 250 L/ha spray volume was applied with an auto sprayer in roadside, railroad and highway sides in May, 1990-91.

RESULT AND DISCUSSION

Fig. 1 shows the result of a trial on roadside. CHOPPER at 75-100 g/ha showed excellent growth suppression on *Miscanthus sinensis* and at 50-100 g/ha on *Artemisia princeps*, for 125 days. The number of seed heads of *M. sinensis* in CHOPPER plots were well controlled compared with untreated plots (50 g/ha = 13/sqm, 75-100 g/ha = 0.6/sqm and Check = 21/sqm). The total fresh weight of target weeds in CHOPPER plots was about one third of the untreated check at 125 DAT (Fig. 2).

Fig. 3 shows the result of a trial on a railroad. The activity of CHOPPER showed some fluctuation among the target weeds. The effective dosages were 75-100 g/ha for *Solidago altissima* and *M. sinensis* and 75 g/ha for *A. princeps*, efficacy lasted for 100 days.

The result of a trial on a highway side is shown in Fig. 4. CHOPPER at 50-100 g/ha showed excellent weed growth suppression of *S. altissiam* for 98 days.

Through the official trials from 1989 to 1991, the efficacy of CHOPPER was authorised by JAPR in 1992 (Table 2).

CHOPPER weed growth suppressor can establish a new concept for industrial vegetation management in Japan.

CHOPPER 1%AS at rates from 50-100 g/ha can maintain the roadside or railroad with short height weeds and will protect these areas from erosion.

Use of CHOPPER can demonstrate significant labor savings for successful weed management compared with normal manual weeding (Fig. 5).

Table 1. Industrial vegetation management in Japan

Segment	Land area weed infested (ha)	Area required for maintenance (ha)	Actual sprayed area (ha)	Actual manual weeding area (ha)
Highway	100,000	12,000	1,500	3,700
Railroad	42,000	39,800	10,000	4,000
River	300,000	243,750	0	13,700
Industries	44,000	44,000	20,000	15,000
Airport	900	900	0	900
Local Government	55,000	5,500	900	2,000
Electricity	100	50	0	30
Total	542,500	346,000	32,400	39,330

Industrial estimation

Table 2. The label of CHOPPER 1%AS as a weed growth suppressor.

Site	Use objective	Target weeds	Application timing	Dosage	Spray volume
Railroad Highway	Weed growth suppression	MISSI PHRCO IMPCK FESAR DACGL ADLHI AOXOD SOOAL RUMOB PUELO	Weed growth stage (plant height, 50 cm tall and below)	50-100 g a.i./ha	250 L/ha

MISSI: *Miscanthus sinensis*
IMPCK: *Imperata cylindrica*
DACGL: *Dactylis glomerata*
AOXOD: *Anthoxanthum odoratum*
RUMOB: *Rumex obtusifolius*
PHRCO: *Phragmites communis*
FESAR: *Festuca arundinacea*
ADLHI: *Arundinella hirata*
SOOAL: *Solidago altissima*
PUELO: *Pueraria lobata*

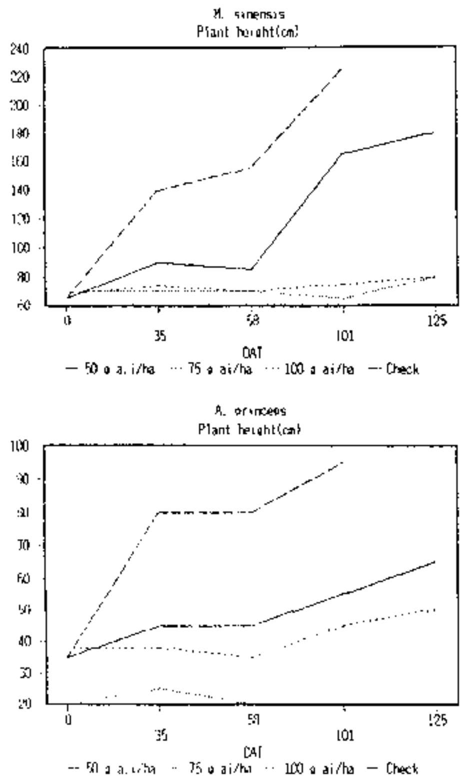

Figure 1. Effect of CHOPPER on roadside.

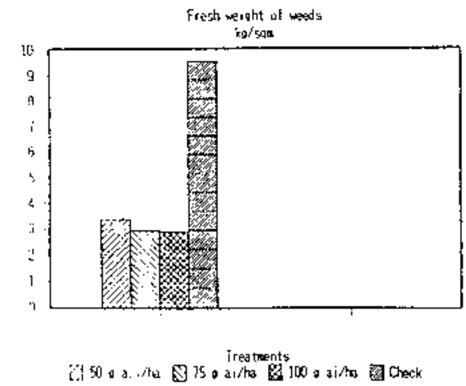

Figure 2. Effect of CHOPPER on weed weight.

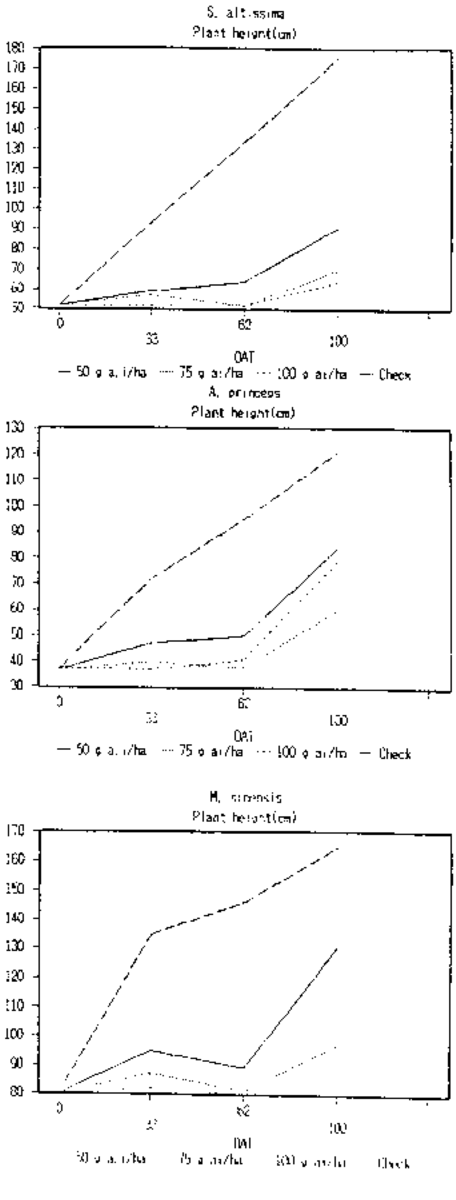

Figure 3. Effect of CHOPPER on railroad.

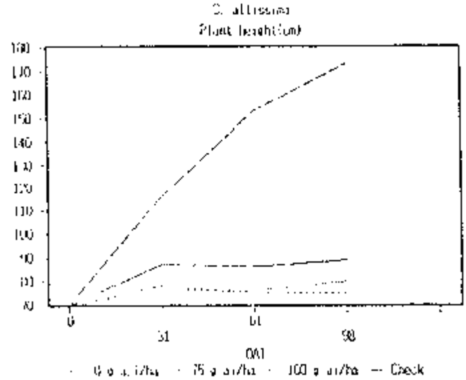

Figure 4. Effect of CHOPPER on highway side.

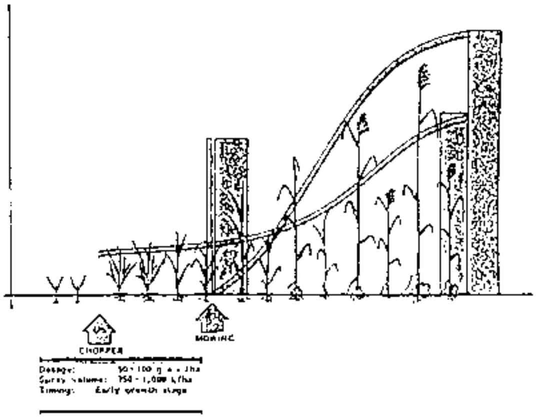

Figure 5. The general effect of CHOPPER for industrial vegetation management.

LIBERATION THINNING IN PEAT SWAMP FOREST IN SARAWAK

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Summary. Liberation thinning were carried out one year (LT1) and ten years (G10) after logging in the Jemoreng Permanent Mixed Peat Swamp Forest plots in 1971 and 1992 respectively. The logged over peat swamp forest had various distributions of woody forest weeds, reserved and protected timber trees. At LT1, the percentage of the various diameter breast height (DBH) of the woody forest weeds was 59.5% of 20-41 cm, 37.1% of 42-62 cm and 3.4% of >62 cm. At the G10 treatment, narrow range of DBH of the woody forest weeds were taken. The size distribution of woody forest weeds at G10 was 41.4% of 10-19 cm DBH, 42.5% of 20-29 cm DBH, 10.5% of 30-39 cm DBH, 2.5% of 40-49 cm DBH, 1.8% of 50-59 cm DBH and 1.3% of >60 cm DBH. The distribution of trees at G10 was 11.9 for protected trees, 75.2% for reserved trees and 12.8% for woody weeds.

INTRODUCTION

The selective management system in forestry is widely practised in Malaysia. This system is adopted with the intention that current harvest will not jeopardise future yield by leaving sufficient residual trees that assume to be matured in the next cutting cycle (5). The success of this ultimate aim can only be achieved with the knowledgeable and suitable techniques of silvicultural treatments. Thus good stand conditions will satisfy all the requirements for tree growth and result in high survival, rapid growth and early maturity of crop species (2).

Liberation thinning is one of the major sivilcultural activities in the logged-over peat swamp and mixed dipterocarp forests particularly in Sarawak. This treatment is defined as the process of selecting as many as possible, ideal and desirable crop trees of "listed species" which have survived logging, and liberating the best of them from competing with trees of less value, leaving others untouched (3, 4, 1). This paper will report the activity, general technique employed during the silvicultural field treatment and the composition of both commercial and weed species carried out at Jemoreng Mixed Peat Swamp Permanent Forest in Sarawak.

METHODS

Two treatments were caried out at Jemoreng Mixed Peat Swamp Permanent Forest with the area of 1152 ha. The area was divided into 24 blocks, i.e. 48 ha per block in order to treat the area systematically. The first treatment (LT1) was conducted in 1971 or one year after felling. This regenerated forest was also treated in 1992 as G10 treatment. Before G10 treatment, diagnostic sampling at 1% intensity was carried out in 1979 or 10-12 years after felling. This area was found to have adequate stock of desirable species (74.9%), weighted mean basal area of 22.32 m2/ha. The weighted basal area of selected desirable (LD) is 2.36 m2/ha. Thus the remaining basal area is 19.96 m2/ha or 89.43% of the total standables. The regeneration potential crop trees consisted of Kapur paya (*Dryobalanops rappa*), Merantis (*Shorea* spp.), Sepetir paya (*Copaifera palustris*), Ako (*Xylopia corisfolia*), Kepayang babi (*Mezzettia leptopoda*), Kelampu (*Sandoricum emarginatum*), Kumpang paya (*Horsfieldia crassifolia*), Nyatoh jangkar (*Palaquium walsurifolium*).

In the field operation, six crews were deployed. Each crew consisted of seven men. Each crew member was allocated with different work task. A labourer was assigned to divide the 48 ha block (600x800 m) into strips, each 40 m wide parallel to the longer side of the block. The boundaries were marked with red plastic flagging for guiding the crews. Cutting should be at the minimal level and chopping of the desirable and acceptable species (including saplings and seedlings) was also avoided. Each crew should have an officer who is familiar and good at identifying tree species. A labourer assist him in marking these trees that he had reserved or rejected by painting them with a short line or a cross. This two-men unit moved within the strip in a zig-zag manner., recording, marking and Diameter Breast Height (DBH) measurement for all suitable trees of desirable and acceptable species for reservation.

One staff member leads three labourers, each equipped with an axe, chisel, poison kettle and a note book and a pencil following closely behind the two men who scouted for reserve trees. For tree poisoned, he kept a "gate-count" by species and diameter class. The trees to be poisoned were marked either by knife slash or cross by crayon. He also kept a "gate-count" by species and diameter classes for the trees reserved by the identification team.

RESULT AND DISCUSSION

Chai (1) reported that Modified Malayan Uniform System, Liberation Thinning and Relics Removal could stimulate diameter increments of the reserved trees. The mean periodic diameter annual increment of reserved trees of Shorea spp. of Modified Malayan Uniform System varied from 1.21 to 1.52 cm, Liberation Thinning from 1.02 to 1.32 cm, and Relics Removal from 0.88 to 0.95 cm and Control treatment from 0.52 to 0.72 cm. In both LT1 and G10 treatments, reserved trees were the most dominant group (Table 1 and 2). The number of protected trees was almost the same number as those from weed species. The percentage of poisoned trees was ranging from 10.0% to 12.8%. The slight increment of the percentage of weed population probably due to their rapid regeneration after the LT1 treatment. This was evident by the high percentage (>80%) of weed population from 10-29 DBH (Table 3). The huge number of weed species at this size proved the weakness of limiting the minimal size of weed trees from 20 cm DBH for poisoning.

Table 1. Percentage of protected, reserved and weed species in LT1 and G10 of Jemoreng Peat Swamp Permanent Forest

Treatment	Percentage		
	Protected	Tree group reserved	Weed species
LT1	12.6	77.4	10.0
G10	11.9	75.2	12.8

Table 2. Number of trees from different tree groups varied in size from G10 treatment

Tree group	Total number of trees					
	Tree size [BDH (cm)]					
	10-19	20-29	30-39	40-49	50-59	>60
Protected	8823	5498	2790	1104	418	175
Desirable	9873	6255	4462	2511	769	262
Acceptable	35155	25616	9652	3055	746	214
Other	7787	6640	4348	826	233	41
Poisoned	8368	8598	2126	499	366	256

Table 3. Number of poisoned trees varied in sizes

Treatment	Distribution of trees (%)					
	DBH 9cm)					
	10-19	20-29	30-39	40-49	50-59	>60
LT1	59.5		37.1			3.4
G10	41.4	42.5	10.5	2.5	1.8	1.3

The sivilcultural technique of Liberation Thinning required experienced and trained personnels and workers. They should be familiar with its concept and be able to identify most of the common trees species in the peat swamp permanent forest. The implementation of Liberation Thinning should also emphasize on the activity of present conservational and bio- diversity principles. A thorough understanding of the biological and ecological characteristics towards which vegetation management prescriptions are directed. In the enumeration of the technique, the personnels and workers should varify clearly the ethnobotanical importance and modes of horticultural for individual forest species including weed species and climbers. Thus the selected species which had been identified could be conserved for future needs and as source of food for wildlife.

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DEVELOPMENT OF HERBICIDE RESISTANCE IN ANNUAL RYEGRASS IN THE CROPPING BELT OF WESTERN AUSTRALIA

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Summary. Annual ryegrass, *Lolium rigidum*, samples from the cropping belt of Western Australia were screened for herbicide resistance. In the wheat - pasture rotation, the relationship between the number of SU applications received in the field and the level of resistance determined in the glasshouse bioassay accounted for 67% of the variance in the data. The number of 'fop' (aryloxyphenoxypropionate) applications in the wheat - lupin rotation accounted for 49% of the variance. After repeated use of 'fops', some ryegrass populations had developed cross-resistance to the other chemical groups. There is an urgent need for farmers to adopt an integrated system of weed management where herbicides are just one of the tools to be used.

INTRODUCTION

Unlike crops, weeds are genetically variable species, some such as ryegrass more variable than others. This diversity allows weeds to evolve mechanisms to cope with selection pressures imposed on them by the environment. There are documented cases of weeds that have evolved resistance to high levels of SO_2 in polluted urban environments (1). In agricultural systems, practices such as summer fallowing have been shown to select for biotypes with longer seed dormancy allowing the weed seeds to carry over to the following crop (2). Herbicides are probably the strongest selection pressure that the weeds have to contend with, therefore it is not surprising that herbicide resistance is being reported in an increasing number of weeds (4).

For the last 10 years or so, farmers in Western Australia and other southern Australian states have relied heavily on selective herbicides for weed control. From 1980 to 1989, the total area of crop sprayed in Western Australia increased from 3.9 to 9.5 million ha, while the total area cropped during the same period remained relatively static around 5 million ha. On average, each cropped hectare in the State is sprayed twice a year for weed control.

In order to document the impact of this substantial herbicide use, extensive testing of ryegrass samples from Western Australian farms was carried out in 1991/92 with two main objectives:

(a) to determine the rate of development of resistance in ryegrass in the cropping belt; and
(b) to determine whether different rotations influenced the rate of resistance build-up.

MATERIALS AND METHODS

Ryegrass populations were tested for herbicide response in an air-conditioned glasshouse (18° day/12°C night). About 300 populations of ryegrass from different areas of the wheatbelt were tested for their herbicide resistance status. For most of these populations, information on herbicide usage in the field was available.

Seeds of ryegrass were imbibed in water for 24 h before they were transferred to a cabinet maintained at 4°C for 7 days. In earlier studies, this vernalisation process was found to promote uniform and synchronised emergence of ryegrass. Seeds were then taken to the glasshouse and sown in pots each containing about 1 kg of a loamy sand. Seeds were covered with the soil to a depth of about 10 mm and the pots were watered to field capacity. A balanced nutrient solution was applied to the pots at sowing and then 3 and 6 weeks after sowing. Pots were watered regularly as required to maintain the soil near field capacity.

Herbicides were sprayed with a sprayer calibrated to deliver a spray volume of 200 L/ha at a pressure of 200 kPa. A sulfonylurea (SU) herbicide, triasulfuron, was applied as a post-plant pre-emergence treatment at 12.5 and 25.0 g a.i./ha, the day after planting. Diclofop-methyl (aryloxyphenoxypropionate - 'fop') at 281.25 and 562.5 g a.i./ha and sethoxydim (cyclohexanedione - 'dim') at 47.25 and 94.5 g a.i./ha were sprayed at the Z12-13 stage of ryegrass. Herbicide rates used were half and full label rates registered for the control of ryegrass in Western Australia. A non-ionic wetting agent (BS1000) at 0.25% (vol./vol.) was added to both the post-emergence herbicide treatments.

The experiments were terminated 8 weeks after planting, by which time all the susceptible plants had died. At harvest, healthy plants were cut at the soil surface and shoot fresh weight was recorded. The shoot growth of ryegrass under any treatment was expressed as a percentage of the fresh weight of the unsprayed plants from the same sample.

The relationships between herbicide usage for the sampled paddocks and herbicide responsiveness in the glasshouse (relative shoot fresh weights) were determined by fitting a Gompertz curve to the data using GENSTAT.

RESULTS AND DISCUSSION

Type of resistance. Cross-resistance appeared quite frequently where farmers relied primarily on the 'fop' herbicides for weed control (Fig. 1). Out of the 51% populations that had 'fop' resistance, 42% had cross-resistance to either the SU's or the 'dims' or both 'dims' and SU's. This type of cross-resistance was very unpredictable and varied in its spectrum from paddock to paddock, even on the same farm with similar herbicide use patterns.

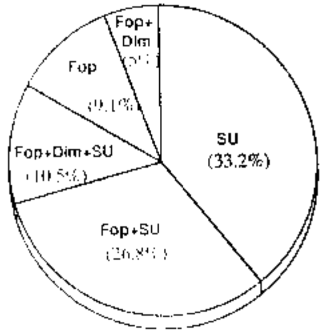

Figure 1. Types of resistance detected in ryegrass populations in Western Australia in 1992.

However, where resistance had developed through the use of the SU herbicides, it was specific to the ALS inhibiting herbicides and cross-resistance to the other herbicide groups was not detected. Because of the great genetic variability in ryegrass populations, several mechanisms of resistance and cross-resistance are known to exist (3).

Rate of resistance development.

'Fop' resistance As can be seen in Fig. 2 (a), 'fop' resistance could be detected in every ryegrass population that had received 6 or more applications of this herbicide group. A non-linear relationship between the number of herbicide applications and the level of resistance accounted for 49% of the variance in the data. Samples near the top limit of the confidence intervals of the means developed resistance with as few as 4 applications. The rate of resistance development by ryegrass in the wheat - lupin and wheat - pasture rotations was quite similar.

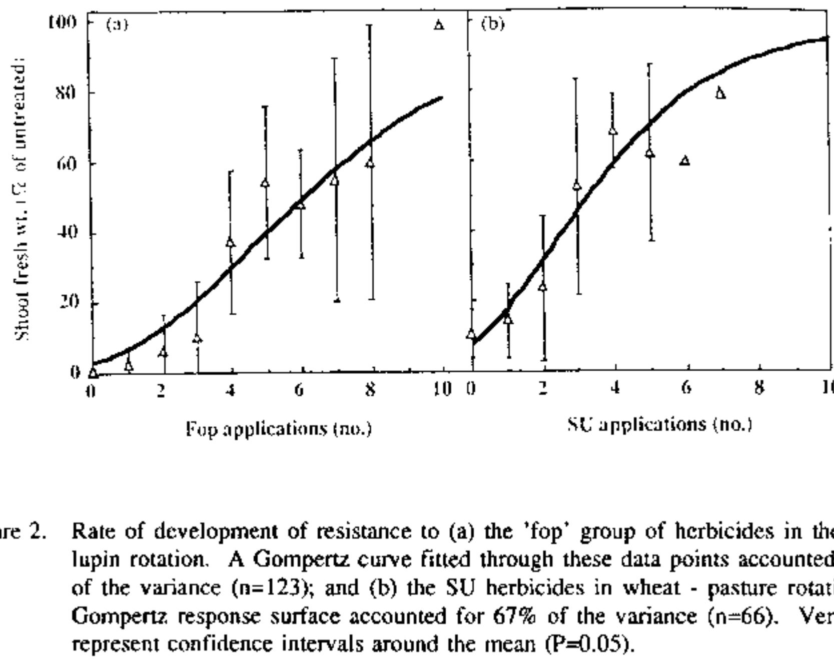

Figure 2. Rate of development of resistance to (a) the 'fop' group of herbicides in the wheat - lupin rotation. A Gompertz curve fitted through these data points accounted for 49% of the variance (n=123); and (b) the SU herbicides in wheat - pasture rotation. The Gompertz response surface accounted for 67% of the variance (n=66). Vertical bars represent confidence intervals around the mean (P=0.05).

SU resistance. SU resistance was found to be developing on Western Australian farms at an alarming rate (Fig. 2 b). Invariably it took only 4 applications of the SU's for ryegrass to develop resistance. Due to grazing by sheep and a lower frequency of herbicide use, the wheat - pasture rotation was considered to be relatively safe from herbicide resistance. Our results clearly show that the rate of development of resistance to highly effective and residual herbicides, such as the SU's, is not delayed by pasture rotations as currently used by the vast majority of farmers in Western Australia.

As described earlier (Fig. 1), some of the samples from wheat - lupin rotation with 'fop' history showed cross-resistance to the SU herbicides. This affected the fit of the Gompertz curve, because even at zero SU applications, some ryegrass populations had a fairly high level of SU resistance (up to 40%). However, by taking out samples that had received 3 or more 'fop' applications, where cross-resistance could have developed, this problem was overcome and the relationship accounted for 52% of the variance.

The relationship between the number of herbicide applications received in the field and the level of resistance determined in the glasshouse bioassay was more variable for the 'fop' herbicides as compared to the SU's (Fig. 2). This means that management factors which delay the development of resistance are more likely to be found for 'fops' than for SU's.

The herbicide revolution in weed control technology has been accompanied by an intensification of crop production throughout southern Australia. Over the last 4-5 years matters have been made worse by the decline in wool prices which has seen further shortening of rotations to include more frequent cropping (i.e. lower sheep numbers). There has also been a swing towards early sowing to achieve higher grain yields. Such factors have further increased farmers' reliance on selective herbicides for weed control. The consequences of over-reliance on selective herbicides are now apparent in Western Australia and some of the other southern Australian states where an ever increasing number of herbicide resistant ryegrass populations are being added to the tally each year.

Farmers are now being urged to correct the imbalance that has existed in the favour of herbicides over the last 10-15 years. Herbicides should be regarded just as one of the tools in an integrated weed management kit. At present this tool is quickly getting blunted by resistance and over-use. There are no new herbicides on the horizon and, even if there were, resistance to them could also develop at a rate similar to that we have documented for the 'fop', 'dim' and SU herbicides. Due to the high level of fitness of the resistant-types, it is not enough just to have pastures in the rotations. What is more important is to effectively control the weeds in pastures with options including grazing, spray-topping, and mechanical topping, that cannot be used in the cropping phase. In continuous cropping systems, there needs to be a greater emphasis on non-chemical methods of weed control and their integration with the selective herbicides.

ACKNOWLEDGEMENTS

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DETERMINATION OF THE EXTENT OF HERBICIDE RESISTANCE IN SOUTHERN NSW

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Summary. A random survey of southern NSW farms was undertaken to determine the extent of herbicide resistance in annual ryegrass (*Lolium rigidum*). Seed was collected from 161 farms and screened in pots for resistance to diclofop-methyl. Twenty two samples exhibited resistance, six of which had a very high level of resistance. However no pattern emerged with respect to geographical distribution. It can be expected, from this base level , that a substantial increase in the incidence of resistance will occur quickly unless herbicide usage practices are changed. Related resistance management issues are currently being addressed by way of a farmer questionnaire.

INTRODUCTION

Herbicide resistance is an increasingly important problem. Australia-wide resistance has been detected in at least five weed species (4). The extent of herbicide resistance is best illustrated by a recent telephone survey which indicated that some 3000 Australian farms have herbicide resistant ryegrass (3). In NSW more and more cases are being identified each year. This will continue , unless farmers practise integrated weed management (IWM) (2).

Surveys have demonstrated that annual ryegrass populations in Australia, resistant to diclofop-methyl, can be found in most areas where annual ryegrass occurs. One such survey in South Australia in 1988 detected resistance in approximately 9% of annual ryegrass samples screened. It also found that no susceptible samples had received more than four applications of diclofop-methyl (1).

This paper reports on the preliminary findings of a random survey which aims to determine the extent and distribution of diclofop-methyl resistance in annual ryegrass across southern NSW.

METHODS

Surveyed farms were selected at random from maps of the defined area, using grids to ensure a relatively even spread of collection sites. Letters were sent to 250 farmers seeking their cooperation in the survey, with 161 positive respondents. Annual ryegrass seed samples were collected in late 1991 from paddocks in crop. No paddock histories were known or obtained prior to the collection and screening process. Collected seed was threshed and cleaned in early 1992.

Experiments were carried out between April and August in a poly house with sides open to the weather.

Screening for resistance to diclofop-methyl was done in the following manner. Aluminium trays were used containing 750mL of a coarse sandy loam soil. Trays were sown with 0.2g of annual ryegrass seed and watered as required. Following germination, trays were thinned to twenty seedlings and diclofop-methyl was applied at the 2 to 4 leaf stage in a spray cabinet.

Four rates of diclofop-methyl (0, 188, 375 and 750g a.i./ha) were applied in 90L/ha of water. A non-ionic surfactant was added at 0.25% v/v. All treatments were replicated through time and arranged in a randomised block design. Results were recorded 28 days after treatment (DAT) using the criterion of less than 85% control at the 375g a.i./ha rate, as the indicator of herbicide resistance. Analysis of two replicates is provided.

RESULTS AND DISCUSSION

The effectiveness of control by diclofop-methyl is shown in Table 1. Using the above criterion as indicating resistance, the data shows twenty two samples, approximately 14%, having significant resistance. Of these, six samples (approximately 4%) had a very high level of resistance whereby no commercial result could be expected from the application of diclofop-methyl.

Table 1. Number of samples (total 161) in each control category 28 DAT

Control (%)	Rate of diclofop-methyl (g a.i./ha)		
	188	375	750
85-100	70	139	153
70-84.9	66	12	2
50-69.9	18	4	0
0-49.9	7	6	6

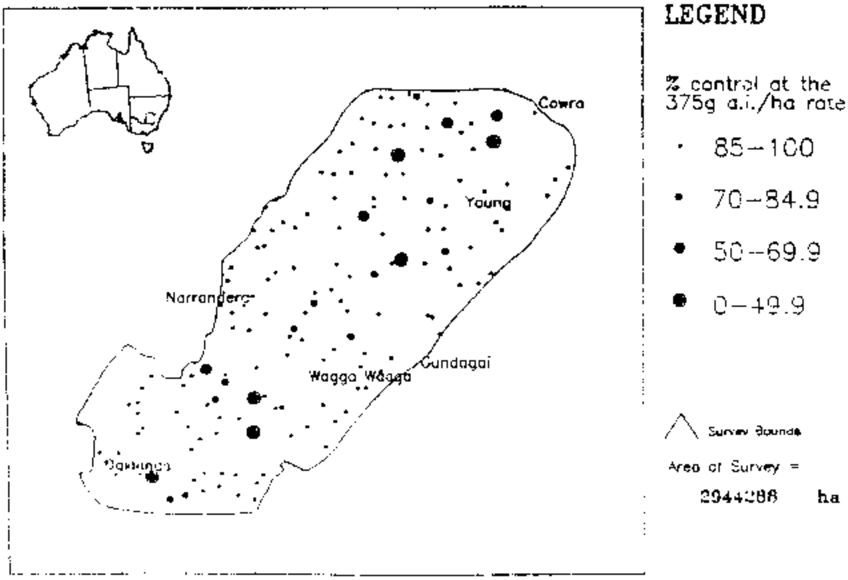

Figure 1. Area of southern NSW surveyed, showing the distribution of diclofop-methyl resistant annual ryegrass (showing all 161 farms).

No pattern has emerged with respect to their distribution within the sampling area (Fig. 1), thus indicating that influences external to the farm have not been significantly effective in respect of resistance development.

The interrelationship between the incidence of resistance and farm management practices is being addressed by way of a farmer questionnaire, which was sent to participating farmers in late 1992. From this the basis for the development or otherwise of resistance will be clarified. The information collected will be used to develop specific strategies for the amelioration of the problem, so as to minimise its spread within the region.

ACKNOWLEDGEMENTS

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HERBICIDE RESISTANCE COMMUNICATION IN WESTERN AUSTRALIA

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Summary. Farmers in the Western Australian wheatbelt are well aware of herbicide resistance (96%). However, they need to be encouraged to keep accurate spray records and chemical groupings need to be better understood. Farmers also need to be encouraged to have a test done to determine current resistance status before making weed control decisions. The concept of rotating crops, pastures and chemicals to delay the development of herbicide resistance is reasonably well understood by farmers but some of the less popular choices for delaying herbicide resistance, such as delayed seeding, need to be better explained. This paper presents the results of a survey of farmers and advisers and provides details of a proposed information package on herbicide resistance.

INTRODUCTION

A communication campaign about herbicide resistance and the availability of a testing service was carried out in Western Australia in 1991. There is now a high level of farmer awareness of herbicide resistance and in this study we attempted to find out what farmers still needed to know about this problem so that we could improve the transfer of information to them.

The objectives were to:

(a) determine the current state of herbicide resistance knowledge, values, attitudes and beliefs amongst farmers and all those engaged in the sale of and/or giving advice on the use of herbicides; and
(b) formulate a communication strategy to address specific gaps in knowledge and to correct misconceptions regarding herbicide resistance.

METHODS

Cereal producers, with a property size exceeding 750 ha were chosen at random from the Agriculture Protection Board computer database. The number of farms selected from each Shire was in proportion to the total number of farms in the sample. A telephone survey of 150 farms was carried out by Insight Research Australia Pty Ltd in February 1993.

The results were tabulated on the basis of the regional sub-divisions used in the Department of Agriculture's wheat variety recommendations which correspond with low, medium and high rainfall regions.

A survey form was also mailed to all of the people thought to be giving advice on herbicides in Western Australia. A total of 354 surveys were mailed to Department of Agriculture advisers (45), private consultants (52), chemical company representatives (54) and reseller representatives (203). Responses were obtained by telephone from those who did not respond by mail. There were 148 usable replies to the farmer survey; 39, 43 and 66 from low, medium and high rainfall regions respectively.

RESULTS AND DISCUSSION

Herbicide resistance status. All of the farmers surveyed used herbicides on their farm and 96 percent of them had heard of weeds developing resistance to herbicides.

Farmers were asked if they had ryegrass or wild oat populations on their farm that had survived a selective herbicide application for no apparent reason; 31 percent said yes, 66 percent said no and 3 percent did not know. The number of herbicide failures increased as rainfall decreased but this trend was not statistically significant.

Of the farmers surveyed, 5.4 percent had a ryegrass herbicide resistance test done in 1992. Although not significant, the percentage varied between rainfall zones with 10.3, 2.3 and 4.5 percent of farmers from low, medium and high rainfall zones respectively having a test done.

A significant but expected finding was that only 57 percent of farmers keep accurate paddock records of herbicide use. This figure was only 44 percent in the low rainfall zone where the largest proportion of farmers had tested for herbicide resistance.

Cropping intensity. Farmers were asked to indicate the percentage of their farms in crop each year and these percentages were cross-tabulated with rainfall zones. The percentage of farm in crop varied significantly between rainfall zones (Fig. 1.). The crop component increased significantly as rainfall decreased. Most farmers in high rainfall cropped between 20 and 40 percent of the farm.

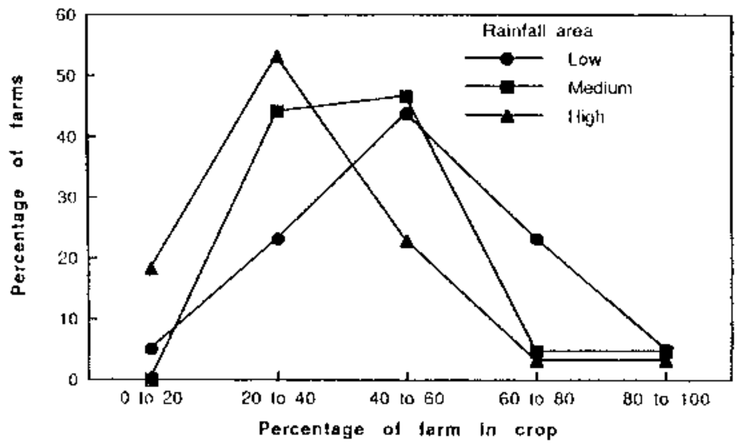

Figure 1. Variation in the percentage of farm in crop according to rainfall zone.

Farmers in medium rainfall cropped between 20 and 60 percent of the farm, the broadest band. Farmers in low rainfall cropped most intensively with most in the 40 to 60 percent category and about 20% in the 60 to 80 percent category.

Knowledge of herbicide resistance. When asked how many applications of a selective herbicide would be necessary to develop herbicide resistance in ryegrass, less than half of the farmers knew the correct answer and more than one quarter did not know how many applications it would take. In contrast, the majority of representatives from the manufacturers, resellers, consultant and Government advisory groups gave a correct answer.

Our current knowledge of herbicide resistance in ryegrass indicates that once resistance has developed to a particular herbicide, the population may never become susceptible to that herbicide again. On this basis, 90.5 percent of farmers did not correctly answer this question with more than half not prepared to commit themselves to an answer. It was of concern that 36 percent of farmers believed that ryegrass populations would become susceptible again. An even greater proportion of farm advisers believed that ryegrass populations would become susceptible again.

Knowledge of herbicide groups. Farmers were given 4 commonly used herbicides and asked if they had used them or not. They were then given 4 chemical groups, 'fops', 'dims', 'SUs' and triazines, and asked to place each chemical in its correct group. Over two thirds of farmers could not place commonly used herbicides in their correct chemical groups. In comparison, over 90 percent of farm advisers were able to correctly group these herbicides. There were some regional differences for farmers' use of herbicides with a lower percentage of Glean® and Hoegrass® users in high rainfall areas. There was also a tendency for farmers in high rainfall areas to be less knowledgable about herbicide groupings than in the other 2 rainfall areas.

Perceived value of management options. Farmers and advisers were asked to rank a list of weed management options according to their value (high, low or of no use) in delaying the development of herbicide resistance on their farm (Table 1).

Farmers in low rainfall areas were significantly less enthusiastic about cutting a weedy crop for hay to prevent seed set. Those in higher rainfall areas viewed more favourably the option of delayed seeding compared to those in low rainfall areas. Most low rainfall farmers considered the delayed seeding option of no use. Burning the stubble was considered to be of low or no use.

Advisers agreed with farmers on the ranking of the 3 most valued options; effective spraytopping, rotation of herbicides and introducing a longer pasture phase. They also agreed with the ranking of cutting a weedy crop for hay (5th) and using trailing bins (8th). Both farmers and farm advisers ranked below label rates as the least useful option to delay the development of herbicide resistance. Farmers gave a higher value to autumn 'tickle' and delayed crop seeding to get an extra weed kill than did the farm advisers. However, resellers favoured autumn 'tickle' more highly than did other farm advisers. In contrast to farmers, manufacturers, consultants and government advisers were strongly against using selective herbicides in the pasture phase. Manufacturers were very strongly against this practice. Resellers were more in agreement with farmers. All farm adviser groups were much more in favour of burning crop or pasture stubble to kill weed seeds than were farmers.

Farmers and advisers were asked if Hoegrass resistant ryegrass swamped their crop this year, what is the likelihood that they would take the following action (Table 2).

The overwhelming majority of farmers said they would harvest the crop and switch to pasture if Hoegrass resistant ryegrass swamped their crop. Farmers in medium and high rainfall areas were again more likely to cut the crop for hay than those in low rainfall areas. Farmers in low and medium rainfall areas were more willing to burn stubble than those in high rainfall areas.

Farm advisers were largely in agreement with each other regarding their advice to a farmer who had a crop swamped with Hoegrass resistant ryegrass. The only major difference was that manufacturers were more strongly in favour of using modified headers to capture ryegrass seeds. In contrast to farmers, farm advisers were more strongly in favour of cutting the crop for hay rather than harvesting the crop and switching to pasture. Farm advisers ranked harvesting the crop with a modified header more highly than did farmers. Farm advisers gave a lower ranking to the value of grazing the crop with sheep than did farmers. Both farmers and farm advisers gave a low ranking to harvesting the crop and burning the crop stubble to kill ryegrass seeds.

Table 1. The perceived value to weed management options (1 = highest value).

Management option	Farmers	Advisers
Effective spray-topping and grazing pasture before cropping	1	1
Rotation of herbicide groups	2	2
Introducing a longer pasture phase in the rotation	3	3
Autumn 'tickle' to stimulate weed germination before seeding	4	6
Cutting a weedy crop for hay to prevent seed-set of weeds	5	5
Delaying crop seeding to get an extra weed kill	6	9
Not applying selective herbicides in the pasture phase	7	4
Using trailing bins behind the header to remove weed seeds	8	8
Burning crop or pasture stubble to kill weed seeds	9	7
Application of herbicides at below label rates	10	10

Table 2. Action or advised if Hoegrass resistant ryegrass swamped a crop (1 = highest value)

Action taken	Farmers	Advisers
Harvest the crop and switch to pasture to reduce ryegrass	1	2
Harvest the crop and switch to another herbicide next year	2	4
Cut the crop for hay or hay-freeze to prevent seed set of ryegrass	3	1
Graze the crop with sheep to prevent seed set of ryegrass	4	6
Harvest the crop and burn the crop stubble to kill ryegrass seeds	5	5
Harvest with a modified header to capture ryegrass seeds	6	3

Perceived value of testing. In the year after Hoegrass resistant ryegrass swamped their crop, 75 percent of farmers said they would have a test done before deciding on an alternative herbicide and 21 percent said they would not have a test done but switch to an alternative herbicide. In contrast, 94 percent of farm advisers said they would recommend a test be done before deciding on an alternative herbicide

New chemicals. On average, 46 percent of farmers thought there were no new chemicals on the horizon which would solve the herbicide resistance problem. Of the remainder, 26 percent thought there were and 26 percent did not know. Farmers in medium and high rainfall areas were more optimistic about new chemicals solving the herbicide resistance problem than were those in low rainfall areas. Farm advisers were less optimistic than farmers with only 14 percent thinking that new chemicals would solve the problem.

How farmers valued advisers and information sources. Farmers were read a list of personal contacts and asked how highly they valued their advice on herbicides. Most popular were the Department of Agriculture advisers and other farmers. Farm consultants also ranked highly. However, farmers placed a lower value on advice from spray contractors, chemical company representatives or resellers. Farmers were read a list of information sources and asked how they valued them for information on herbicides. As would be expected, there was close correlation between how farmers rated personal contacts and associated information sources. Information sourced from the Department of Agriculture, field days, seminars, and local farmer meetings was most highly valued by farmers. In contrast, Information sourced from chemical companies, videos and resellers was given a relatively low rating.

Extension initiatives. The major initiatives of the 1993/94 program will include a media liaison and communication program of regular articles for the press, television and radio coverage. The integrated weed management story will be broken down into seasonal components which can be communicated in a more timely manner. A survey is also planned for early 1994 to identify any shift in farmers' knowledge and enable us to re-focus the communication strategy.

An update and reference package will be prepared for all advisers servicing the industry in Western Australia. It will include a plastic binder "Herbicide Resistance Information". The binder will house the regular updates, including the new herbicide resistance bulletin and relevant Farmnotes, which we intend to mail to industry advisers. A presentation package will include a set of 5 or 6 overheads together with a video case study on herbicide resistance.

A diary is being produced which will facilitate farmers' record keeping of paddock use of herbicides and other weed control records. The diary will also contain oth
er essential information such as herbicide groupings. A herbicide groups chart will also be produced separately as an A2 sized wall poster and a laminated A4 sized chart.

ACKNOWLEDGEMENTS

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HERBICIDE RESISTANCE IN A WILD OAT BIOTYPE IS DUE TO MUTANT ACETYL COENZYME A CARBOXYLASE

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Summary. A biotype of wild oat (*Avena sterilis* ssp. *ludoviciana*) in Australia is resistant to a wide range of aryloxyphenoxypropionate (AOPP) herbicides. Possible mechanisms of herbicide resistance in this resistant (R) and a susceptible (S) biotype were investigated. Acetyl-CoA carboxylase (ACCase), the target site for herbicides and a key enzyme of fatty acid biosynthesis, from the R biotype was markedly less sensitive to ACCase inhibiting AOPP (diclofop) and cyclohexanedione (CHD) (tralkoxydim) herbicides than the S biotype. Uptake, translocation and metabolism of [^{14}C]diclofop-methyl were also investigated, but there were no differences between the two biotypes in any of these parameters. Hence, the most probable mechanism of herbicide resistance in this R wild oat biotype is due to a modified form of ACCase.

INTRODUCTION

Wild oats resistant to herbicides have been primarily reported from Canada, USA and Australia (1, 9, 10). In these cases, resistance has occurred following repeated selection with one herbicide or with herbicides from the same class or the same mode of action. Herbicide resistance may be due to the decreased sensitivity of the target site or alteration in uptake, translocation and metabolism of the herbicide. The target site of AOPP and CHD herbicides is acetyl coenzyme-A carboxylase (ACCase), a key enzyme in fatty acid biosynthesis, which catalyzes the conversion of acetyl-CoA to malonyl-CoA (6, 7, 12). Generally, ACCase from grasses is sensitive to both groups of herbicides while that of dicotyledons is insensitive (7, 8). In this paper the mechanism of herbicide resistance in a resistant wild oat biotype has been investigated.

METHODS

Resistant (R) and susceptible (S) wild oat biotypes collected from Bordertown, South Australia in 1989 were used. The R biotype was collected from a field which has been treated with diclofop-methyl and fluazifop-butyl for the previous six years and the S biotype was collected from unsprayed field near the infested area of R biotype (9). Seeds were germinated on 0.6% agar before being transplanted into sterilised potting soil and grown in a growth room. Growth conditions were 20°C, 14 h, 330 μmol photons/m/s light period/16°C, 10 h dark period. Plants at 2-3 leaf stage, the stage normally treated with dicofop-methyl in the field, were used for ACCase inhibition assays. ACCase was extracted and partially purified (13) from both biotypes and the response to herbicides was determined.

Plants at the 2-leaf stage were used for uptake, translocation and metabolism experiments. A solution of 5 mM [^{14}C]diclofop-methyl (a specific activity of 592 MBq/ml) made up in a commercial formulation blank (Hoegrass 36 EC, Hoechst Autralia) was applied as a 1 μL drop of the solution to the leaf axil of wild oat plants. In the translocation experiment, the tissue was divided into small fractions, i.e. meristem (1 cm above the root zone initiation), stem (from meristem up to 2 cm above leaf axil), first leaf, second leaf and third leaf. Each fraction was extracted separately with 80% methanol and the amount of radioactivity was determined by liquid scintillation spectroscopy. Radiolabelled metabolites were separated by using reverse phase HPLC as previously described (4).

RESULTS AND DISCUSSION

Uptake, translocation and metabolism of [^{14}C]diclofop-methyl. Foliar absorption of diclofop occurred readily in both S and R biotypes with maximal uptake within the first 24 h. Very little label could be detected in the first or third leaves at any time. Most of the activity remained in the stem and leaf. Little label was found in the roots of either biotypes (Table 1).

Table 1. The distribution of radioactivity in wild oat seedlings growing in sand culture

Biotype	Time after treatment (h)	^{14}C activity (% of total uptake)		
		Stem	Leaf	Root
Susceptible	140	54	44	2
	180	40	56	4
Resistant	140	58	40	2
	180	43	54	3

In the translocation experiments, most of the label was present in the stem and second leaf of both biotypes. Slightly more radioactivity was found in the second leaf of the R biotype than in the S biotype at any time. At later time periods more of the radioactivity was observed in the upper parts of second leaf in both biotypes. However there was less translocation from the base of the second leaf in the S biotype (Figs 1A and 1B). This may be because the S plants were dying and therefore translocation was reduced.

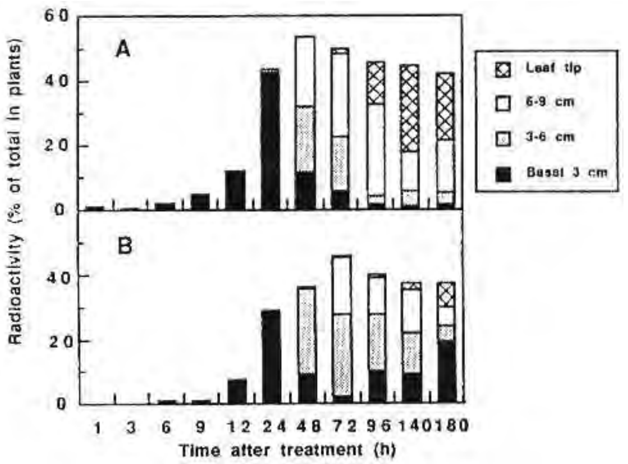

Figure 1. Distribution of [^{14}C]diclofop-methyl in the second leaf of resistant (A) and susceptible (B) wild oat biotypes.

The metabolism of [^{14}C]diclofop-methyl was similar in both biotypes. Conversion of diclofop-methyl to diclofop acid was rapid with less than 50% of applied label recovered as diclofop-methyl in either biotypes by 1 h after application (Table 2). Diclofop acid was slightly greater in the R biotype than in the S biotype at times greater than 12 h after treatment. However, the S biotype showed the herbicidal symptoms whereas the R showed little effect and recovered after 48 h. There were no differences in diclofop-methyl absorption, translocation and metabolism between the two biotypes of wild oat, which suggests that these processes do not account for the the mechanism of herbicide resistance. This is similar to the results found in diclofop resistant wild oats (1) or sethoxydim resistant annual ryegrass biotype SLR 3 (13).

Table 2. Diclofop metabolism in susceptible and resistant wild oats 1, 12, 24 and 48 h after treatment (HPLC data)

Biotype	Time after treatment (h)	^{14}C activity (% of total uptake)		
		Diclofop-methyl	Diclofop acid	Metabolites
Susceptible	1	47 ± 3	53 ± 1	-
	12	8 ± 1	58 ± 7	34 ± 6
	24	8 ± 3	42 ± 4	50 ± 4
	48	6 ± 1	25 ± 3	69 ± 1
Resistant	1	41 ± 1	59 ± 2	-
	12	11 ± 1	53 ± 2	36 ± 1
	24	6 ± 1	39 ± 3	55 ± 3
	48	5 ± 1	21 ± 2	74 ± 2

ACCase inhibition by herbicides. Partially purified ACCase from the S biotype, was inhibited by the AOPP and CHD herbicides. The enzyme purified from the R biotype was less sensitive to these herbicides. ACCase from R biotype was 52 times less sensitive to diclofop than ACCase from the S (Fig. 2A) and 3 times less sensitive to tralkoxydim (Fig. 2B). The result is similar to other observations that AOPP herbicides are more potent inhibitors of ACCase than CHD herbicides (3, 10).

At the whole plant level, the R biotype showed high levels of resistance to AOPP herbicides (diclofop, fluazifop, haloxyfop, fenoxaprop, quizalofop, propaquizafop and quinfurop) and a slight increase in resistance to the CHD herbicides (sethoxydim, tralkoxydim and cycloxydim) (9). This is reflected at the ACCase level with the level of resistance of the enzyme being greater for diclofop (52-fold) than tralkoxydim (3-fold). These results indicate that an altered form of ACCase in the R wild oat biotype is responsible for resistance to these herbicides. A similar mechanism of resistance to these herbicides has been reported for annual ryegrass resistant to sethoxydim in Australia (13) and Italian ryegrass resistant to diclofop in USA (3). In contrast, diclofop-resistant wild oats (*Avena fatua*) from Canada and Australia do not have a mutant ACCase (1, 5). In the case of wild oat from Canada, resistance is related to alteration in membrane properties (2). Currently there are over 20 biotypes of wild oats that have devloped resistant to AOPP and CHD herbicides in Australia. The mechanism of resistance in the other biotypes has yet to be determined.

In conclusion, the most probable cause of resistance to a range of AOPP herbicides in the R biotype of wild oat is a mutant form of ACCase.

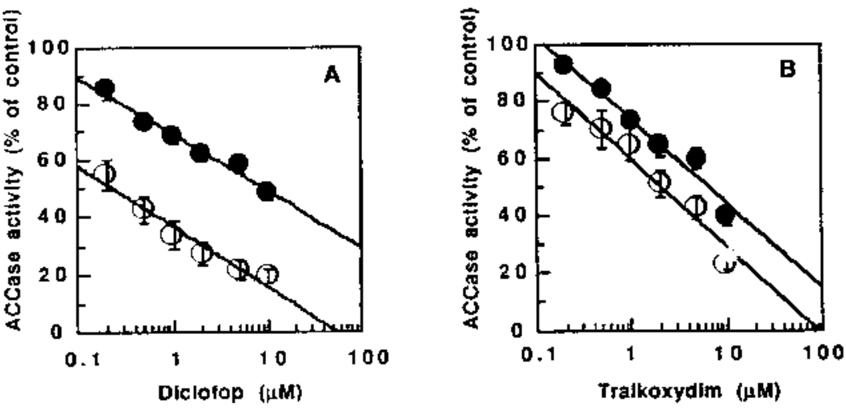

Figure 2. Inhibition of ACCase from susceptible and resistant wild oat biotypes by diclofop (A) and tralkoxydim (B). Open symbols, susceptible; closed symbols, resistant. Experiments were done in duplicate and repeated seven times.

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TOWARDS AN UNDERSTANDING OF THE MECHANISMS OF RESISTANCE TO ARYLOXYPHENOXYPROPIONATE (APP) HERBICIDES IN *ALOPECURUS MYOSUROIDES* (BLACK-GRASS)

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Summary. Resistant biotypes Lincs. E1 and Peldon A1 have fenoxaprop ED_{50} values 27 and 4 times greater than the susceptible (Rothamsted) biotype, respectively. Lincs. E1 and Peldon A1 are 10 and 13 fold more resistant to diclofop, respectively. The target site of these herbicides is acetyl-CoA carboxylase (ACCase). Affinity of ACCase for the substrate acetyl-CoA was similar for all biotypes. ACCase extracted from Peldon A1 and Rothamsted was more inhibited by fenoxaprop and diclofop than ACCase from Lincs. E1. Differences in ACCase inhibition were due to a subset comprising approximately 15% of the Lincs. E1 population. ACCase extracted from this subset was less sensitive to inhibition by diclofop. Absorption and translocation experiments showed that Rothamsted absorbed fenoxaprop-ethyl faster than both the resistant biotypes but there were no significant differences in translocation. Rothamsted contained more herbicidally active fenoxaprop than resistant biotypes 6 to 48 HAT (hours after treatment). The reasons for the lower fenoxaprop content in the resistant plants are under investigation but probably accounts for their ability to survive fenoxaprop treatment.

INTRODUCTION

Populations of *Alopecurus myosuroides* in the United Kingdom have developed multiple herbicide resistance to herbicides in unrelated chemical groups with different modes of action (8,9). In one population (Peldon A1) the major mechanism of resistance to chlorotoluron is enhanced herbicide metabolism (6). Two multiple-herbicide resistant populations, from Essex (Peldon A1) and Lincolnshire (Lincs. E1), show high levels of resistance to herbicides in the APP family of herbicides. The mechanism(s) of herbicide resistance of these biotypes to APP herbicides is the subject of this investigation.

The APP herbicides, along with cyclohexanedione (CHD) herbicides, inhibit the enzyme ACCase. Several mechanisms which contribute to APP resistance have been reported. Resistant plants may contain a modified ACCase which is less inhibited by herbicides (1,10). APP resistance has also been correlated with rapid cell membrane repolarisation after herbicide removal (3), however the mechanistic basis of this response and its role in whole plant resistance is poorly understood (4). A population of *Lolium rigidum* has developed high levels of resistance to APP and CHD herbicides not based on target site mutations (7). This population has multiple mechanisms, including enhanced metabolism of diclofop (5) and cell membrane repolarisation (3), one or both of which can contribute to an individual's resistance.

Uptake, translocation and metabolism of fenoxaprop and inhibition of ACCase by APP and CHD herbicides are compared in two resistant biotypes of *A. myosuroides* and a susceptible to determine the mechanism(s) of resistance.

METHODS

Seeds were collected in fields in Hertfordshire (Rothamsted), Essex (Peldon A1) and Lincolnshire (Lincs. E1), UK. The Rothamsted biotype was collected from an area untreated with herbicides. Peldon A1 and Lincs. E1 biotypes were collected from fields where herbicides had failed to control *A. myosuroides*. Methods used to compare resistance to herbicides at the whole plant level have been described previously (8).

Inhibition of ACCase activity by five herbicides, diclofop, fenoxaprop, fluazifop, sethoxydim and tralkoxydim, at final concentrations between 0 and 100 μM was measured as previously described (10) and the affinity of ACCase for acetyl CoA in extracts from the three biotypes measured at concentrations between 0 and 600 μM acetyl CoA. To determine if the small differences in ACCase inhibition by diclofop between Lincs. E1 and Rothamsted was characteristic of the whole population, seeds of Lincs. E1 were germinated on 6% (w/v) agar supplemented with 100 μM fluazifop and herbicide inhibition profiles of ACCase extracted from survivors were compared with those of the bulk of the Lincs. E1 population.

To measure the absorption and translocation of fenoxaprop, ^{14}C fenoxaprop-ethyl (spec. act. 971 MBq/ g) was applied to the second leaf of three leaf stage plants and 12, 24, 48, 72 or 96 HAT, unabsorbed herbicide washed from the leaves, plants sections oxidised separately and uptake and translocation quantified by liquid scintillation counting (2).

Metabolism of fenoxaprop-ethyl was determined by applying a 2 μL drop of ^{14}C fenoxaprop-ethyl to the leaf axis, washing off unabsorbed herbicide 3, 6, 12, 24, 48, 72 and 96 HAT and extracting the herbicide and metabolites with 80% (v/v) methanol. Parent herbicides and metabolites were separated by HPLC and the quantity of herbicide and metabolites expressed as a percent of total radioactivity in the extract.

RESULTS AND DISCUSSION

Effect of Inhibitors of ACCase on growth of intact plants. Peldon A1 and Lincs. E1 show varying levels of resistance to both APP and CHD herbicides compared to the susceptible Rothamsted. Lincs. E1 was more resistant than Peldon A1 to fenoxaprop (ED_{50} ratios to Rothamsted of 27 and 4) but showed similar resistance to diclofop (13 and 10), quizalofop (8 and 6); fluazifop (7 and 6); and the CHD herbicides sethoxydim (2 and 1.5) and tralkoxydim (16 and 13). There was no direct relationship between levels of resistance and the family of herbicide, APP or CHD.

ACCase Activity. Affinity of ACCase extracted from the three biotypes for acetyl-CoA was similar. Fifty percent of maximum enzyme activity was obtained at 70, 71 and 81 μM acetyl-CoA in Lincs. E1, Peldon A1 and Rothamsted, respectively.

ACCase activity of all three biotypes was inhibited by APP herbicides, diclofop, fenoxaprop and fluazifop and CHD herbicides, tralkoxydim and sethoxydim. Lincs. E1 shows consistently less inhibition of ACCase than Rothamsted, the susceptible biotype. If ACCase insensitivity in Lincs. E1 was a property of the whole population, it would be unlikely to protect plants from herbicide toxicity. While Lincs E1 may show small differences in inhibition kinetics, it is also possible some individuals in the population have an insensitive ACCase while the majority of this field collected population does not. A subset of approximately 15% of the population selected on 100 µM fluazifop contained ACCase less inhibited by diclofop than that of the unselected population. Continued selection of Lines. E1 with APP herbicides would be expected to increase the frequency in the population of this less sensitive ACCase.

Absorption and Translocation of Fenoxaprop-ethyl. Absorption of ^{14}C fenoxaprop-ethyl was low, with an average of 29% after 12 hours, increasing to 44% 72 HAT. Translocation from the applied leaf was limited, reaching an average of 4% 72 HAT. Rothamsted absorbed more ^{14}C fenoxaprop-ethyl, but there were no significant differences between biotypes in amount of herbicide translocated from the site of application. Differences in uptake or translocation of APP herbicides have not been previously shown to contribute to herbicide resistance.

Metabolism of Fenoxaprop-ethyl. Extracts from both resistant biotypes contained a smaller proportion of herbicidally active fenoxaprop than extracts from susceptible 6 to 48 HAT. Reduced fenoxaprop content in the resistant biotypes may be due to slower fenoxaprop-ethyl conversion to fenoxaprop, or to enhanced binding of fenoxaprop-ethyl, making it unavailable for breakdown to fenoxaprop, or to enhanced detoxification of fenoxaprop to inactive conjugates. These possibilities are under investigation.

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COMPETITIVE ABILITY OF THE PARAQUAT-RESISTANT BIOTYPE OF *ERIGERON PHILADELPHICUS*

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Summary. Competitive ability of a paraquat-resistant biotype of Philadelphia fleabane, *Erigeron philadelphicus* L., was evaluated by comparing the photosynthetic characteristics and population demography of sensitive and resistant biotypes. There was no significant difference in the photosynthetic characteristics between the two biotypes. In a 3-year experiment paraquat was sprayed 5-6 times each year on a mixed population which initially consisted of an equal number of individual plants of the two biotypes. The ratio of the number of individuals of the paraquat-resistant biotype to the sensitive one increased under repeated paraquat applications but remained constant under the control conditions. The study suggests that the paraquat-resistant biotype may be more competitive than the sensitive biotype when paraquat is continuously applied.

INTRODUCTION

A paraquat-resistant biotype of Philadelphia fleabane, *Erigeron philadelphicus* L., was first discovered in Japan in 1982 (4). The ratio of the number of individuals of the resistant biotype to the sensitive one seems to increase in Japan.

In this study, the competitive ability of the resistant biotype was investigated by comparing the light-photosynthesis curves in individuals of both biotypes and tracing the ratio of the number of the resistant biotype to the sensitive one under repeated paraquat applications and under the control conditions.

METHODS

Young plants of the paraquat-sensitive biotypes of Philadelphia fleabane were collected from the roadside in our Institute. Prior to transplanting, the sensitivity to paraquat was tested according to the method outlined in another paper (3). Young resistant plants were collected from a chestnut orchard where most of the plants were known to be resistant. Prior to transplanting, the resistance to paraquat was also tested, and the plants that were confirmed to be resistant were used in further experiments.

On 6 March 1990, sensitive and resistant plants were transplanted in plastic pots and grown to analyse the photosynthetic characteristics. Photosynthetic activity of the leaves from the sensitive and resistant biotypes was measured by enclosing a cut leaf in an assimilation chamber and by monitoring the CO_2 concentration of the air at the inlet and outlet of the chamber with an infrared gas analyzer (Fuji Electrics ZRC).

At the same time, the sensitive and resistant plants were transplanted alternately in 4 blocks in the field as shown in Fig. 1. In 2 blocks (1 and 2) each plant was planted 20 cm apart from the neighboring plant, while in the other 2 blocks (3 and 4) 30 cm. After the plants took root, paraquat (1,1'-dimethyl-4,4'bipyridinium dichloride) solution was sprayed to the 2 blocks (1 and 3) 3 times in 1990 at the rate of 28.8 g a.i./ha, which is equivalent to about 1/20 strength of the usual application rate. In 1991, paraquat was sprayed to the 2 blocks 5 times and in 1992 6 times, at a rate of 57.6 g/ha which is about 1/10 of the usual application rate. In the other 2 blocks (2 and 4) no paraquat solution was sprayed. A leaf was collected from each plant that appeared in a quadrat placed in 5 different areas of each block, and the resistance to paraquat was examined for each collected leaf by the method outlined in another paper (3), twice in 1990, 4 times in 1991 and 3 times in 1992. The percentage of resistant plants was calculated.

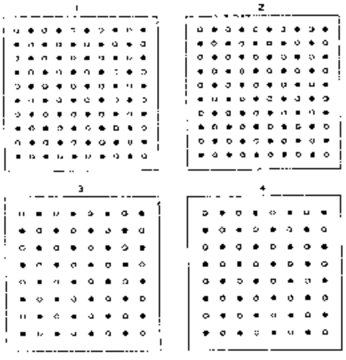

Figure 1. Diagram illustrating the planting scheme of Philadelphia fleabane. Open circles show the paraquat-sensitive plants, closed circles the resistant ones. In blocks 1 and 2 each plant was planted 20 cm apart from the neighboring one. In blocks 3 and 4 each plant was planted 30 cm apart. In blocks 1 and 3 the paraquat solution was sprayed repeatedly, while in blocks 2 and 4 paraquat was not sprayed.

RESULTS AND DISCUSSION

Photosynthesis. Light-photosynthesis curves of the leaves in the paraquat-sensitive and resistant biotypes are shown in Fig. 2. Under the photosynthetically active radiation of 540 µmol/m^2/s, the photosynthetic activity of a leaf of the sensitive biotype was 7.1 µmol/m^2/s while that of the leaf of the resistant biotype was 6.5. The dark respiration of a leaf of the sensitive biotype was 1.9 µmol/m^2/s while the value was 1.8 in the case of the resistant biotype. No significant differences were observed both in the value of the photosynthetic activity and dark respiration and in the shape of the light-photosynthesis curves.

The present results are not in agreement with the fact that leaves from plants resistant to triazine herbicides (e.g. atrazine), are known to display a much lower photosynthetic ability than the leaves of sensitive biotypes (1, 2).

Population demography. As the difference in the distance of each plant from the neighboring plant at the time of planting did not cause any appreciable differences in the rooting and population demography, the results for plots 1 and 3 and for plots 2 and 4 were pooled. Fig. 3 shows the relationship between the time of herbicide application and the ratio of the number of resistant plants to the number of total plants examined. In 1990, the ratio remained constant regardless of paraquat application, presumably due to the very low concentration of the herbicide. In 1991, 4 applications of the herbicide increased the proportion of resistant plants to

78% by the end of August. In 1992, the applications of the herbicide led to further increases. Throughout the 3 year period, the ratio under control conditions did not show any appreciable changes, values ranging between 42% and 60%.

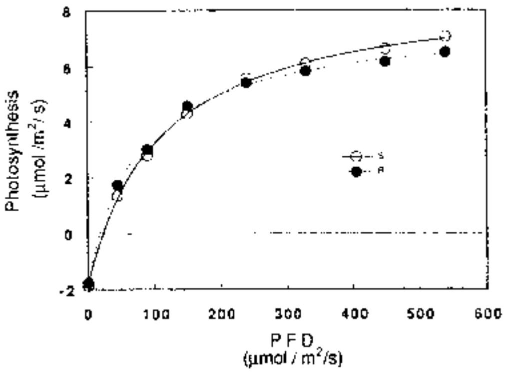

Figure 2. Light-photosynthesis curves of Philadelphia fleabane leaves from the paraquat-sensitive (S) and resistant (R) biotypes. PFD: Photon flux density.

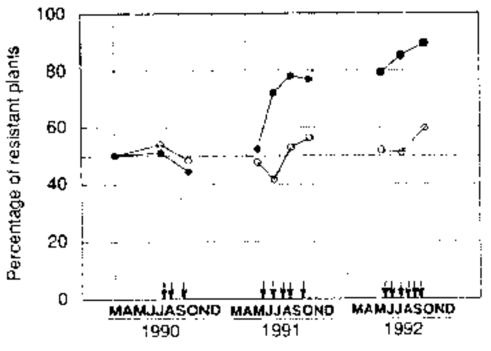

Figure 3. Changes in the percentage of paraquat-resistant plants to the total plants examined. Arrows at the bottom of the figure show the time when paraquat was applied. Open circles: percentage under the control conditions; closed circles: percentage under repeated paraquat applications.

These results indicate that the proportion of resistant ratio increased under the pressure of the herbicide at a much lower concentration than that of the usual application, but that the ratio remained fairly constant for at least 3 years without herbicide application. Therefore, it is assumed that the resistant biotype may dominate areas where paraquat is applied periodically and may co-exist with the sensitive biotype where paraquat is not sprayed.

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CROP SENSITIVITY TO RESIDUES OF ATRAZINE AND CHLORSULFURON IN A SOIL-FREE SYSTEM

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Summary. Although reduced crop growth resulting from residues of herbicides has been well documented, little is known about the levels of herbicide residues that cause crop damage. A soil-free system was used to study the growth response of the five main summer crops of south-east Queensland, sorghum (*Sorghum bicolor*), maize (*Zea mays*), sunflower (*Helianthus annuus*), cotton (*Gossypium sp.*), and soybean (*Glycine max*), to atrazine and chlorsulfuron. Crop sensitivity to atrazine and chlorsulfuron is measured in a soil-free system, eliminating the confounding effect of soil adsorption thus allowing for extrapolation to different soil types. Sunflower was the crop most sensitive to atrazine, with 0.01 mg ai/L reducing seedling growth by 10%. Soybean was the most sensitive crop to chlorsulfuron, tolerating only 0.08 µg ai/L chlorsulfuron. Results from the soil-free system will be validated under field conditions for prediction of safe recropping intervals.

INTRODUCTION

In the northern grain belt of Australia, farming practices are changing in recognition of the value of conservation cropping aimed at reducing soil erosion and maximising water infiltration and soil water storage. This has resulted in increased use of herbicides as the primary means of weed control and a reduction in tillage practices. The herbicides atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) and chlorsulfuron {2-chloro-N-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino] carbonyl] benzenesulfonamide} obtain effective residual broadleaf weed control both in crop and into the fallow. The widespread adoption of residual herbicides is limited, however, by the variation in their persistence in different environments. This results in over-conservative recropping intervals in some situations or excessive carry-over causing injury to following sensitive crops (1).

Before recropping intervals can be predicted for different environments, the sensitivity of different crops needs to be determined and the level of herbicide in the root zone measured or predicted. The response of five summer crops to a range of atrazine and chlorsulfuron concentrations is measured using a soil-free system. This system eliminates the confounding effect of soil adsorption, and thus, allows extrapolation to different soils.

METHODS

Five summer crops were grown in a soil-free system with ten rates of either chlorsulfuron or atrazine in two experiments. The crop species studied included sorghum cv. Pac 810, cotton cv. Siokra L22, soybean cv. Manark, sunflower cv. Hysun 24, and maize cv. GH5010. Each experiment was a completly randomised block design with six replications. Similar techniques were used in both experiments.

The soil-free system was a two pot bioassay system modified from the hydroponic bioassay described by Stalder and Pestemer (4). A 150x140 mm diam. lined pot held the nutrient and herbicide solution and a 100x95 mm diam. lined pot with a layer of 20 mm basalt pebbles and filled with sterilised sand used to support the plant. A 120 mm pot saucer, with a 75 mm diameter centre piece removed, was placed on top of the larger pot as the lid with the 100 mm pot placed inside the saucer. A 150 mm cotton wick was used to draw up the solution culture from the lower to the top pot.

Five seeds each of the crop species were sown into the sand in 100 mm pots. Ten atrazine dose levels (0, 0.005, 0.01, 0.025, 0.05, 0.1, 0.25, 0.5, 1, 10 mg a.i./L) or ten chlorsulfuron dose levels (0, 0.1, 0.5, 1, 2.5, 5, 10, 50, 100, 500 µg a.i./L) were added to 1 L of commercial hydroponic nutrient solution (Manutec hydroponic nutrients®) and adjusted to pH 6.5. Nutrient solutions were replenished twice weekly with fresh solutions containing the same constitution.

At 7 d after sowing (DAS), plants were thinned to one plant per pot and algaecide (Howes Olympic®) applied. At 21 DAS, plant height and herbicide injury symptoms were recorded, plants were harvested, and fresh and dry weight of shoot growth was determined. Crops were grown under glasshouse conditions with the average day and night temperature of 16°C and 31°C.

A logistic equation was fitted to the data as a function of herbicide concentration by non-linear regression using Graphpad 3.1 statistical package:

$$Y = A + \left[\frac{B - A}{1 + (10^{C}/10^{X})^{D}} \right]$$

where Y is shoot fresh weight (% of control) and X is the herbicide concentration (mg atrazine/L; µg chlorsulfuron/L). A and B denote the upper and lower asymptote, C is log (ID_{50}), the concentration of 50% seedling growth inhibition and D the slope at ID_{50}. The logistic equation was also used to derive ID_{10} and ID_{30} values, the herbicide concentration that inhibits 10% and 30% seedling growth.

RESULTS AND DISCUSSION

Response to atrazine. Shoot fresh weight response to atrazine differed significantly between the five crops (Fig. 1). The sequence of increasing crop tolerance was sunflower < cotton = soybean < sorghum < maize. There was a 15-fold difference in the concentration of atrazine required for 30% inhibition of fresh shoot growth between sunflower and sorghum (Table 1). This difference was even greater between sunflower and maize (Fig. 1). At 0.25 mg/L, sunflower seedlings were killed and cotton and soybean severely injured. Although atrazine is registered for use in both sorghum and maize, sorghum shoot growth was also reduced at 0.25 mg/L but maize shoot growth was only affected at concentrations greater than 1 mg/L. Our ID_{50} values for sunflower and soybean are similar to values measured by Pestemer *et al.* (3) also using a hydroponic system but different cultivars.

Plant stunting was visible 7 DAS. Chlorosis of oldest-leaf tip margins was evident on sunflower, cotton, and soybean 5 d later, followed by necrosis developing and plant death in the higher concentration treatments. Maize developed interveinal chlorosis, stunting, and lacked vigour in the 10 mg/L treatment 14 DAS.

Table 1. ID_{10}, ID_{30}, and ID_{50} values of cotton, maize, sorghum, soybean, and sunflower for atrazine and chlorsulfuron.

Crop	Atrazine (mg/L)			Chlorsulfuron (µg/L)		
	ID_{10}[a]	ID_{30}[b]	ID_{50}[c]	ID_{10}	ID_{30}	ID_{50}
Cotton	0.08	013	0.16	0.23	0.51	0.85
Maize	-	-	-	0.14	0.28	0.43
Sorghum	0.10	0.32	0.67	0.25	0.53	0.84
Soybean	0.08	0.12	0.16	0.08	0.21	0.39
Sunflower	0.01	0.02	0.04	0.13	0.28	0.46

[a]ID_{10}=Herbicide concentration that inhibits shoot growth by 10%
[b]ID_{30}=Herbicide concentration that inhibits shoot growth by 30%
[c]ID_{50}=Herbicide concentration that inhibits shoot growth by 50%

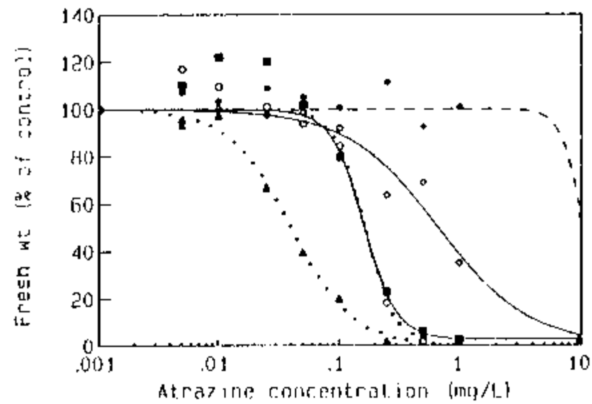

Figure 1. Relative fresh shoot weight of cotton (○ ... ○), maize (*--*), sorghum (◊—◊), soybean (■—■), and sunflower (▲ ... ▲) to atrazine concentrations in a soil-free system.

Response to chlorsulfuron. The difference in seedling response to chlorsulfuron between the crops (Fig. 2) was less than atrazine with only a two fold difference in ID_{30} between soybean and cotton or sorghum (Table 1). All species were highly sensitive resulting in a dramatic plant response over a narrow concentration range. The order of decreased sensitivity was soybean < maize = sunflower < sorghum = cotton. Our results for sorghum are similar to values measured by Haigh and Ferris (2) using the same system.

Treatment differences were evident 7 DAS with stunting and poor emergence of all crops at higher concentrations. Shoot growth ceased followed by chlorosis, terminal spikelet death, necrosis, and plant death. A purple to rust colour appeared on the base of the leaf of sorghum, sunflower, and soybean.

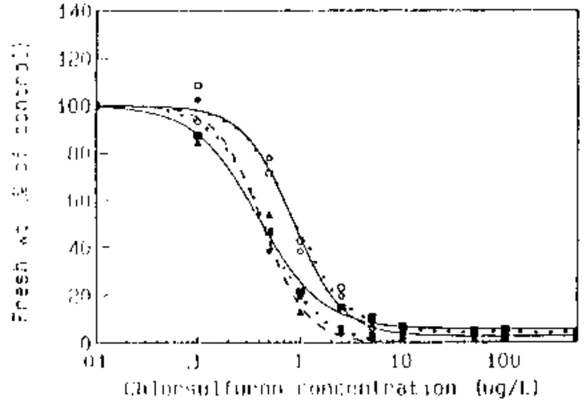

Figure 2. Relative fresh shoot weight (% of control) of cotton (○ ... ○), maize (*--*), sorghum (◊—◊), soybean (■—■) and sunflower (▲ ... ▲) to chlorsulfuron concentrations in a soil-free system.

<u>Implications</u>. For the measured crop sensitivity (ID values) to atrazine and chlorsulfuron to be of use for predicting crop response in the field, the plant available residue level in the root zone at planting needs to be measured or predicted. The investigation by Walker *et al.* (5) of the influence of soil factors on persistence, movement, and activity of atrazine and chlorsulfuron will greatly assist in predicting herbicide residues at planting.

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TOLERANCE OF PERENNIAL RYEGRASS/WHITE CLOVER PASTURES TO FIVE SULFONYLUREA HERBICIDES

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Summary. The tolerance of perennial ryegrass, *Lolium perenne*/white clover, *Trifolium repens*, pastures to five sulfonylurea herbicides, the standard phenoxy herbicides (2,4-D and MCPA) and asulam was compared in four field trials during 1991 and 1993. With the exception of asulam, all the herbicides were more damaging to white clover than to perennial ryegrass. For the sulfonylurea herbicides, autumn applications were more damaging to white clover than were spring applications. Thifensulfuron (15-18.8 g/ha) applied in spring was the least damaging of the sulfonylurea herbicides producing only short term suppression of perennial ryegrass, while white clover damage was similar to that of 2,4-D. Tribenuron, primisulfuron, chlorimuron and metsulfuron severely suppressed perennial ryegrass for up to 3 months and removed much of the white clover within 2 months of application. Of the sulfonylurea herbicides evaluated in these trials, thifensulfuron appears to have the most potential as a broadcast treatment for selective control of some pasture weeds. Use of the other sulfonylurea herbicides should be limited to spot or directed applications due to their lack of selectivity to both perennial ryegrass and white clover.

INTRODUCTION

Sulfonylurea herbicides are highly active against a wide spectrum of broadleaf and grass weeds. While seed germination is not usually affected, subsequent root and shoot growth may be rapidly and severely inhibited (1). The need for such broad spectrum, low dosage compounds with greater crop selectivity is an important factor contributing to the rapid success of this group of chemicals. Since their initial development in the late 1970's several herbicides of the sulfonylurea group have been evaluated and registered for a wide variety of uses. These range from total vegetation control to selective weed control in crops such as rice, cereals, soya beans and maize, as well as for aquatic weed control (1,2,3). Worldwide very little effort has been devoted, however, to their development and use for weed control in pastures.

Early development work in New Zealand indicated that certain sulfonylurea herbicides had potential for control of pasture weeds such as ragwort, *Senecio jacobaea*, docks, *Rumex* spp, buttercups, *Ranunculus* spp., and thistles (4,5), and two chemicals were registered for spot treatment in the late 1980's. Experimental work has since concentrated on the tolerance of pasture species to broadcast applications of some sulfonylureas as they may offer an alternative to the phenoxy herbicides in certain situations, for example in the vicinity of horticultural crops or for treatment of pasture weeds that are resistant to phenoxy herbicides. This paper reports results of field trials on the tolerance of perennial ryegrass and white clover based pastures to five sulfonylurea herbicides applied in autumn or spring.

METHODS

Four field trials were conducted at the Ruakura Agricultural Centre near Hamilton between 1991 and 1993, with a trial being laid down in the autumn and spring of each year. All trials were on predominantly perennial ryegrass/white clover pastures and grazed by sheep, except Trial 4 which was grazed by dairy cows. The soil type in all cases was a Horotiu sandy loam with pH ranging between 5.4 and 5.8 and the organic C between 8.1 and 9.8%. In Trial 1 several sulfonylurea herbicides were tested for their effects on pasture production and compared with asulam, 2,4-D + clopyralid and the phenoxy herbicide standards, 2,4-D and MCPA (Table 1). The most promising treatments were further evaluated in the subsequent trials. All trials were of a randomised block design with plot-sizes of 2x10 m and 4 or 6 replications.

The herbicide treatments were applied approximately 10 days after grazing with a compressed gas powered precision sprayer delivering 300 L/ha at 210 kPa, using flat fan nozzles. A non-ionic wetting agent, Citowett, was added to the sulfonylurea herbicides at 0.2% v/v. Treatments in the two autumn trials were applied on 11 June 1991 (Trial 1) and 15 April 1992 (Trial 2) while the spring treatments were applied on 17 th October 1991 (Trial 3) and 17 th September (Trial 4). No rainfall was recorded within 6 hours after application in any trial.

The effects of treatments on the twp pasture species were determined at regular intervals by visual assessments (comprising an estimate of growth suppression and physical damage such as discolouration and distortion) by at least two observers. The pasture production was determined at critical times of damage by moving two 9x0.5 m strips from each plot. After recording the grenn weights, subsamples were taken for dry matter analyses. At most harvests further sunsamples were taken for pasture composition analyses by herbage dissection. the trials were grazed the day after the mowing and trimmed if required before spelling till next assessment.

As the data from the two autumn trials were compatible and the variances were similar, results from Trials 1 and 2 were converted to precent of untreated and are presented in one table. Least significant differences (l.s.d.'s) presented here are from anlayses variance performed on untransformed data as the data did not require transformation.

RESULTS AND DISCUSSIONS

Visual damage. All the sulfonylarea herbicides produced some damage symptoms on the pasture species. In perennial ryegrass a purplish discolouration developed within 2 weeks of spraying, staring at the tip of the leaf blades and, more often, on the midrib side of the blade. The discolouration turned to yellow in the more damaging treatments and eventually to brown as the foliage died. The oldest or largest leaf of a tiller appeared to be the most affected. In the case of white clover the leaflets and petioles showed a reddish purple discolouration initially, turning yellow with time. New clover leaves were very small and stolon growth was greatly reduced for several weeks after treatment. This effect persisted for several months with the more active herbicides. In the asulam treatments both perennial ryegrass and white clover showed yellowing within 3 weeks of treatment. For the phenoxy treatments perennial ryegrass showed no apparent effect but white clover plants were rapidly twisted and distorted with typical auxin type damage.

Most of the discoloured tissue was removed from the plots by the first grazing after treatment. Following this, all plots treated with either sulfonylurea or phenoxy herbicides contained noticeably less white clover. By the summer months the untreated plots as well as those treated with asulam were conspicuous by the large number of white clover flowers in them.

Autumn trials. The two autumn trials (Table 1) were conducted to test a range of candidate herbicides at the time of year that they would be applied for best control of certain target weeds, i.e. ragwort and nodding thistle, Carduus nutans, and therefore included some members of the group known to have activity on these weeds (5). The results showed that tribenuron, primisulfuron and metsulfuron were too damaging to both perennial ryegrass and to white clover and that chlorimuron was very damaging to white clover. The suppression of these species also allowed an increase in the 'other grasses' component which remained high until the spring. The level of damage to perennial ryegrass by thifensulfuron was similar to most of the other sulfonylurea herbicides but the amount of white clover damage was much less, particularly at the lower application rates. Asulam also suppressed perennial ryegrass and white clover production for a short time but was less damaging than the sulfonylurea herbicides, especially to white clover. None of the phenoxy herbicides significantly affected perennial ryegrass but they all severely reduced white clover. The low rate of MCPA caused less white clover damage than any other treatment except asulam, while 2,4-D produced damage similar to thifensulfuron. The high rate of MCPA and the 2,4-D plus clopyralid treatments were considerably more damaging, almost eliminating white clover from the pasture for more than 6 months (Table 1). It should be mentioned here that such high rates of the phenoxy herbicides and the 2,4-D/clopyralid mixture are currently being used to control nodding thistles that have become tolerant to phenoxy herbicides.

Overall, thifensulfuron was the least phytotoxic of the sulfonylurea herbicides tested, although it still proved highly damaging to white clover. At rates of 15-18.8 g/ha, required for control of common pasture weeds (4), it probably cannot be considered as a broadcast treatment for perennial ryegrass/white clover based pastures in the autumn.

Table 1. Effect of herbicide treatments applied to pasture in the autumn, Trials 1 and 2.

Treatments	Rate (g/ha)	Perennial ryegrass Dry matter (% of untreated)		White clover Dry matter (% of untreated)		White clover Damage (%)
		6 WAT*	12 WAT	6 WAT	12 WAT	30 WAT
thifensulfuron	15	61.9	117.2	11.1	27.6	32.5
thifensulfuron	18.8	50.7	97.0	11.4	25.9	25.0
thifensulfuron	30	51.4	90.1	9.0	11.0	37.5
primisulfuron	30	44.9	103.9	24.0	1.0	55.8
primisulfuron	60	35.6	88.2	27.5	0.6	40.8
tribenuron	20	56.8	109.4	33.4	0	65.0
tribenuron	30	48.8	86.9	27.7	0	77.5
metsulfuron	3	50.9	81.0	29.1	0	85.0
chlorimuron	30	92.0	123.0	30.7	0	35.0
asulam	1600	72.0	99.2	75.6	98.7	0
MCPA	1125	93.6	136.2	32.0	73.1	5.0
MCPA	2250	89.8	140.1	0	31.2	72.5
2,4-D + clopyralid	2160 + 30	83.3	142.2	11.0	3.1	80.4
2,4-D	2160	81.6	129.3	15.7	33.62	33.5
untreated		100	100	100	100	0
l.s.d. (P=0.05)		18.7	21.3	11.8	24.4	16.0

* WAT = weeks after treatment.

<u>Spring trials</u>. Previous work on the efficacy of thifensulfuron on various pasture weeds indicated that it might be better tolerated by the pasture species when applied in the spring (4). Results from the two spring trials (Tables 2 and 3) show that although thifensulfuron caused some suppression of perennial ryegrass also in the spring it was for a shorter period, probably due to the faster growth of perennial ryegrass at this time of the year. However, this

suppression was sufficient to reduce the total pasture yield, recorded 2 or 3 weeks after treatment, compared to the phenoxy herbicides.

In the case of white clover also, production was severely suppressed for a shorter time than in the autumn trials, especially in Trial 4 (Table 3) and was not significantly different from the untreated by about 20 weeks after treatment for all but the highest rate. Thifensulfuron resulted in clover damage similar to that of the standard phenoxy herbicides although the results varied considerably between the two trials. This was most likely due to better growing conditions around the time of treatment as Trial 3 was sprayed 1 month later than Trial 4, when the pasture was growing at a faster rate. Recovery of the white clover in all treatments was faster in the spring trials compared to the autumn trials.

Table 2. Effect of herbicide treatments applied to pasture in spring 1991, Trial 3.

Treatment	Rate g/ha	Perennial ryegrass DM (kg/ha)		White clover DM (kg/ha)			
		2 WAT*	8 WAT	2 WAT	8 WAT	21 WAT	32 WAT
thifensulfuron	15	984	446	54.0	70.5	54.6	40.4
thifensulfuron	18.8	820	414	54.0	80.1	51.8	46.1
thifensulfuron	30	851	396	42.2	58.0	34.2	39.5
2,4-D	2160	1196	474	21.3	35.9	41.8	69.0
MCPA	2250	1279	495	19.8	27.2	27.5	40.1
asulam	1600	1191	443	99.2	117.0	71.2	79.1
untreated		1409	450	156.8	128.5	67.0	53.7
l.s.d. (P=0.05)		375	127	23.7	26.2	18.6	19.9

* WAT = weeks after treatment.

Table 3. Effect of herbicide treatments applied to pasture in spring 1992, Trial 4.

Treatment	Rate g/ha	Perennial ryegrass DM (kg/ha)			White clover DM (kg/ha)			
		3 WAT*	6 WAT	9 WAT	3 WAT	6 WAT	18 WAT	27 WAT
thifensulfuron	11.3	914	611	1040	79.8	29.1	627	198
thifensulfuron	15	780	482	977	48.8	6.5	542	155
thifensulfuron	18.8	862	546	1053	109.0	4.8	598	160
thifensulfuron	30	732	489	1080	47.7	3.2	372	185
2,4-D	2160	1022	699	1059	66.3	28.1	459	162
MCPA	2250	1270	549	1071	6.6	22.2	277	130
asulam	1600	969	512	893	76.6	39.6	611	151
untreated		1204	623	1016	120.0	102.6	554	174
l.s.d. (P=0.05)		164	161	221	53.1	11.9	150	47

* WAT = weeks after treatment.

From these results it was concluded that of the sulfonylurea herbicides tested, only thifensulfuron has potential as a broadcast, spring applied herbicide in pastures. The other chemicals, viz. metsulfuron, tribenuron, chlorimuron and primisulfuron, would probably have to be limited to spot or directed applications. They could also offer possibilities for providing effective control of some troublesome weeds in the year before resowing of pastures as discussed by Mitchell *et al* (6) or when a different crop is to be planted before pasture renovation (7). Thifensulfuron has recently been registered for broadcast use in pastures in Germany and Ireland and as a spot treatment in Switzerland. Work is continuing in New Zealand on refining the rates and times of application before it is recommended as a broadcast treatment for control of pasture weeds in the spring.

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THE IMPACT OF DEVELOPING HERBICIDE RESISTANT CROP PLANTS

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Summary. A wide range of technical approaches allows the production of crop plants that are genetically modified to be resistant to a specific herbicide. The agricultural applications of herbicide-resistant crops are wider than simple weed control. The development and introduction of this new technology offers opportunities for enhancing the quality and quantity of both seed and crop production systems.

Wide scale introduction of herbicide resistant crops would have some marked advantages for weed management and hence crop production. The possible environmental impacts associated with developing herbicide resistance in crop plants are examined and the gene flow of herbicide resistance to weeds is judged to be a negligible threat. Specific case studies of genetically modified crops with herbicide resistance demonstrate that there may be marked environmental and production advantages in the new technology. It can be reasonably claimed that the new technology could promote the replacement of some existing herbicides by those that are toxicologically and environmentally more acceptable.

INTRODUCTION

It is possible to develop herbicide-resistant plants by conventional plant breeding techniques. However, recent advances in cellular and molecular biology of plants greatly simplify the development of herbicide resistance in a wide range of crops. The ease with which these genetic manipulations can be made has opened up a number of new applications for herbicide-resistant crops in seed production and agronomic practice, in addition to providing an alternative strategy to conventional weed control.

The potential of this technology has raised public concerns that the development of herbicide-resistant crops could result in the greater use of herbicides. In addition, significant management concerns include the potential transfer of genes encoding herbicide resistance from crops to weeds, and the persistence of volunteer crop plants. Advocates of the technology have generally argued that developing crops with resistance to selective herbicides will have the positive effect of reducing overall herbicide use by promoting the use of more effective and environmentally acceptable chemicals. This paper examines the environmental impacts associated with developing herbicide resistance in crop plants.

DEVELOPMENT OF HERBICIDE RESISTANT CROPS

Genetic variation for different tolerance responses to a variety of herbicides has been detected in a range of crop species. Herbicide tolerance can be cytoplasmically inherited, qualitatively inherited as single dominant or recessive alleles, or quantitatively inherited with several to many loci with varying degrees of additive and dominance gene action. The development of crop plants with improved tolerance to herbicides has been possible by conventional breeding and selection using both qualitatively and quantitatively inherited genes. Herbicide tolerant plants have also been successfully developed through applications of cell culture. Protoplast fusion has proved especially useful for the development of herbicide-tolerant plants by transferring chloroplasts that encode resistance to triazine herbicides, whereas *in vitro* cell selection has allowed new sources of mutant genes to be developed.

The recent development of transgenic plants via genetic engineering offers considerable potential for the development of herbicide resistance. The rapid development of this technology has already resulted in over 135 regulatory approved field trials on transgenic plants with herbicide resistance in a wide range of crops (1).

APPLICATIONS OF HERBICIDE-RESISTANT CROPS

To control weeds the degree of herbicide selectivity to the crop must be sufficient to allow the application of a herbicide at concentrations capable of eliminating weeds, while having minimal or no effect on the economic yield of the crop plant. With effective herbicide-resistance in crop plants, herbicide applications can be delayed until weed control is necessary. The benefits of herbicide-resistance are reduced herbicide applications and hence reduced environmental impacts.

Development of herbicide resistant cultivars provides for a number of agronomic opportunities:

- The development of a broad range of herbicide-resistant crops could be important for establishing effective crop rotations, that allow crops to be grown on herbicide-contaminated soils.

- The independent development of herbicide resistance in different lines of the same cultivar or crop offers a novel management approach for the control of crop volunteers.

- Herbicide resistance offers a convenient approach to achieving crop thinning by blending seed of a herbicide-resistant genotype and a herbicide-sensitive genotype and the sowing of a random mixture. Herbicide application at a later date will eliminate the sensitive plants.

- The development of a cultivar with herbicide resistance offers a convenient approach to eliminate from the seed production fields sources of contamination from seed of the same crop or weeds by applying the appropriate herbicide. Marker genes for herbicide resistance can be effectively used to overcome several problems associated with pollen contamination during hybrid seed production.

DEVELOPMENT OF WEED STATUS AND GENE FLOW OF HERBICIDE RESISTANCE TO WEEDS

The most frequently raised concern about the introduction of transgenic herbicide-resistant plants is the possible spread of the resistant gene beyond the sown crop (3). There are two mechanisms for such spread:

Development of weed status. The potential for a transgenic herbicide-resistant crop to develop weed status depends on the reproductive characteristics of the plant species and the crop in the following rotation. The capacity for transgenic plants to persist in ensuing crop rotations is unlikely to be any different from the existing situation for non-transgenic crops, unless the introduction of herbicide resistance confers a change in ecological fitness. Good husbandry will minimise the numbers of volunteers and existing physical or chemical control strategies should eliminate volunteers that appear.

Gene Flow. Emigration of herbicide-resistant genes from the crop has the potential to occur intraspecifically and interspecifically. In both cases gene flow could arise via pollen or seed dispersal.

The dispersal of pollen beyond the source crop depends on the specific plant species although generally pollen travels a negligible distance (2). Traditional plant breeding techniques have recognised this fact and, as a result, set standard isolation distances for specific crops to prevent pollen-based gene flow contamination of crops grown for seed. These isolation standards take into account the pollen dispersal and outcrossing characteristics. The extension of isolation standards to transgenic crops is an appropriate precaution. Independent of the ability for pollen to disperse beyond its source, the significance of pollen-based gene flow is related to the mating system of receptor species. There are many post-zygotic barriers before ultimate seed production, seedling appearance and gene expression. Successful fertilisation and post-zygotic development could readily occur in cases of intraspecific crossing, but in cases of interspecific crossing or hybridization, the frequency of successful fertilisation is very low (Frankel and Galun, 1977).

Seed emigration from the crop is a function of the crop attaining sexual maturity, and the activity of seed-distributing agents. The spread of viable seed from the sown crop offers the opportunity for the establishment of "weed" populations of the transgenic herbicide-resistant plants. Control would be similar to current practice for volunteer plants.

IMPACTS OF INTRODUCING HERBICIDE-RESISTANT CROPS

To illustrate the possible application of herbicide resistance in crops, two case studies, as they apply in New Zealand have been prepared, using examples of herbicide - crop combinations for which specific herbicide resistance has been developed.

Glyphosate-resistant field tomatoes. Field-grown tomato (*Lycopersicon esculentum* L.) is an important processing crop that has significant weed problems. Wide planting and incomplete plant canopy development provide an ideal environment for a wide range of annual and perennial weeds. Weeds reduce crop yield and create problems for mechanical harvesting. Applying glyphosate to genetically-modified tomato plants would allow a very wide spectrum of weeds to be controlled, including perennial species that are difficult to kill. The risk of crop damage, which can occur with existing herbicide recommendations, can be avoided. The use of glyphosate would provide greater flexibility in the timing of applications for weed control compared with the soil-applied treatments of chloramben, diphenamid and trifluralin. The grass-specific herbicides fluazifop (butyl ester) and quizalofop (ethyl ester) must be used in association with a broadleaf herbicide treatment resulting in significantly greater total herbicide usage. Glyphosate has low toxicity and its rapid degradation and lack of persistence in soil and groundwater make it environmentally acceptable. Soil residue problems with existing herbicide recommendations, such as diphenamid, metribuzin and trifluralin, are significant while chloramben is highly water soluble and a potential risk to groundwater.

Chlorsulfuron-resistant potatoes. Potato (*Solanum tuberosum* L.) is a very important fresh market and processing crop with significant weed competition and weed control problems. In addition post-harvest sprouting of non harvested tubers can create a major volunteer potato problem in subsequent crops. Potato is a long duration crop that is planted in wide rows and involves moulding. These factors generate a significant opportunity for weed establishment, reduction in crop yield and interference with harvesting efficiency. Chlorsulfuron controls most broadleaf weeds and importantly offers some flexibility in the timing of application in relation to the stage of weed development. The short term soil residual activity of chlorsulfuron is of benefit in controlling late emerging weeds. The use of chlorsulfuron on potatoes would eliminate the use of some presently registered herbicides that control an inferior spectrum of broadleaf weeds, or may cause crop damage. Chlorsulfuron could be used with great flexibility and at times that correspond to the appearance of weeds - a practice not possible with some existing products, for example bentazone and metribuzin. Chlorsulfuron does not control some broadleaf weeds, such as black nightshade (*Solanum nigrum* L.) nor grass weeds that are potential problems in a potato crop. Large-scale grass weed problems would necessitate the use of a selective grass herbicide, such as fluazifop (butyl ester). Soil residual activity of chlorsulfuron may restrict the planting of subsequent specific crops. No analysis of the potential for groundwater contamination is available but the risk appears to be slight. The occurrence of weeds with specific resistance to chlorsulfuron is a concern and does not argue in favour of selecting this herbicide.

CONCLUSIONS

Overall the impact of developing and releasing herbicide-resistant plants does not impose an additional environmental risk to that already represented by herbicide use. The release of herbicide-resistant plants establishes a more complex but not necessarily greater risk than is presented by current practice. The development of crop plants that are resistant to specific herbicides should also include analysis of the effects of these herbicides on the environment, particularly their soil persistence, potential for leaching to groundwater, or undesirable bio-accumulation characteristics. Resistance in crops to herbicides that pose the least environmental threat should be the target of genetic engineers.

ACKNOWLEDGEMENTS

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FIELD TESTING OF POTATO LINES GENETICALLY MODIFIED FOR CHLORSULFURON RESISTANCE

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Summary. A field experiment was conducted to evaluate lines of the potato cultivar Iwa that had been genetically modified for chlorsulfuron resistance. Transformed lines with one to three copies of a gene encoding a chlorsulfuron-insensitive form of acetolactate synthase were compared with a non-transformed line.

Crop response was assessed to one and two applications of 20 g/ha chlorsulfuron. In the absence of chlorsulfuron, the non transformed line yielded 80.1 t/ha, which was reduced to 30.6 t/ha by two chlorsulfuron applications. In comparison, the transformed lines showed minimal or no damage in response to the herbicide treatments.

In the absence of chlorsulfuron, the transformed lines had reduced yields in comparison to the untransformed line. This was attributed to somaclonal variation arising during the cell culture and regeneration phase of transformation.

INTRODUCTION

The development of crop plants with resistance to a specific herbicide has been achieved by conventional plant breeding and more recently by the application of plant molecular biology techniques (1, 8). The prerequisites for engineering herbicide resistance in a crop plant are the availability of a suitable cloned gene that confers herbicide resistance and the ability to transform foreign genes into the crop species of interest. The rapid development of plant genetic engineering in recent years has already resulted in over 135 regulatory approved small scale field trials on herbicide-resistant transgenic plants in a wide range of crops (2).

There have been relatively few reports of the performance of genetically modified, herbicide resistant crops under large scale field conditions. The present paper details such an experiment using genetically modified potatoes (*Solanum tuberosum* L.) transformed for resistance to the broad spectrum herbicide chlorsulfuron. Crop & Food Research (formerly Crop Research Division DSIR) developed a series of transformed chlorsulfuron-resistant potato lines of the New Zealand cultivar Iwa (3). These lines resulted from *Agrobacterium* - mediated transformation using the binary vector pKIWI110 (7), with all lines expressing 3 foreign genes: a chimeric selectable marker gene conferring kanamycin resistance (NOS-NPTII-NOS), a chimeric reporter gene conferring ß-glucuronidase activity (35S-GUS-OCS), and a gene encoding a chlorsulfuron-insensitive form of the enzyme acetolactate synthase cloned from a chlorsulfuron-resistant mutant of *Arabidopsis thaliana* L. (5).

METHODS

Three transformed lines were selected for this study, since they showed high levels of resistance to chlorsulfuron and were indistinguishable from the parent cultivar in phenotypic appearance and yield during initial small scale field trials (Conner et al, unpublished results). The 3 lines, SCI1, SCI2, and SCI4 had two, three and one copy of the chlorsulfuron-resistant gene respectively.

The experiment, conducted at the Lincoln Research Farm (Crop & Food Research) was a randomised block, split plot design. Potato genotype was the main plot, consisting of the three chlorsulfuron-resistant lines and a non-transformed line of the cultivar Iwa. Split plot factors consisted of the weed control treatments; hand weeding, a single or a double application of chlorsulfuron and an untreated control. Main plots were 16x6 m and sub plots 8x3 m which were randomly assigned in four replicate blocks. The total experimental area was 1920 m^2.

Regulatory approval for the field trials was received from the Minister for the Environment on 27 October 1989, following submissions to the Interim Assessment Group for the Field Testing and Release of Genetically Modified Organisms.

Seed potatoes were planted on 11 November 1989 in 750 mm rows and grown at optimum soil fertility and with irrigation to maintain soil moisture. Chlorsulfuron was applied as Glean at 20 g/ha in 200 L water as an overall spray on 18 December 1989, when the crop was 150 mm above the top of the mould and again on 20 January 1990, at which stage the crop canopy had achieved almost full cover.

Potatoes were harvested during the third week of May 1990 using a Faun 1600 single row potato harvester. Only tubers from the middle two rows of each plot were used for further analysis. The tubers were graded to establish the yield of table-grade potatoes. Orthogonal contrasts were used to assess significance of difference between treatments and lines.

RESULTS AND DISCUSSION

Weed populations in all treatments were not significant and unlikely to have a major effect on the yield of potatoes. Thus there were limited differences in potato yield between unsprayed and hand weeded plots (Tables 1 and 2). The low incidence of weeds allowed for realistic estimates of the impact of genetic transformation for chlorsulfuron resistance on the yield of potatoes and for determination of the effect of chlorsulfuron on untransformed and transformed lines.

Total yield of potatoes in transformed lines was reduced, compared to the untransformed line in those treatments except for SCI 4 hand weeded not receiving chlorsulfuron (Table 1). In particular the line SCI 1 showed a significant yield penalty. Addition of a single or double application of chlorsulfuron severely reduced yield in the untransformed line (data analysis not presented), but not in the transformed lines. There were significant differences in the yield of table potatoes between all transformed lines and the untransformed line, except between hand weeded, untransformed (62.8 t/ha) and SCI 4 (57.5 t/ha) (Table 2). The unsprayed, untransformed line produced a significantly greater yield of table potatoes than any of the transformed lines, by at least 17.4 t/ha. A single application of chlorsulfuron severely reduced the yield of the untransformed line, without any major yield penalty to the transformed lines. Similarly the double application of chlorsulfuron severely reduced the yield of the untransformed line but allowed a yield of >39.0 t/ha in transformed lines.

The combined results in Tables 1 and 2 indicated that transformed lines produced smaller tubers and a reduced proportion of total yield as table potatoes.

There was no significant crop damage in transformed lines receiving chlorsulfuron treatments. Any yield reduction associated with genetic transformation was not linked to obvious foliar damage.

The total yield of the unsprayed, untransformed line of cultivar Iwa of 80.1 t/ha represents a highly productive potato crop for Canterbury conditions. This was almost 20% greater than the total yield for the corresponding transformed lines SCI 2 and SCI 4, while SCI 1 had an even lower yield (Table 1). This reduced yield of the transformed lines could be attributable to:

1. a yield penalty associated with the possession and expression of the inserted genes,
2. a mutational event resulting from the insertion of the transferred genes into the potato genome,
3. somaclonal variation occurring during the cell culture and regeneration phase of transformation.

Table 1. Total potato tuber yield (t/ha). Contrast between untransformed and transformed lines

	Unsprayed	Hand weeded	Chlorsulfuron applications	
			1	2
Untransformed	80.1	74.4	54.1	30.6
SCI 1	48.7	52.4	61.0^{ns}	57.0
SCI 2	64.7	61.4*	62.0^{ns}	64.4
SCI 4	64.4	70.2^{ns}	63.2^{ns}	66.0

Significant contrasts between untransformed and SCI lines. All contrasts significant at $P<0.01$, except *($p<0.05$) and ns (non-significant).

The first two possibilities are regarded as being highly unlikely or rare events associated with plant transformation (4, 6), whereas somaclonal variation is considered to be of common occurrence and likely to account for the majority of phenotypic variation between transformed lines (4).

The possession of genes for chlorsulfuron resistance conferred a yield advantage for transformed lines under a herbicide regime of two applications (Tables 1 and 2). The absence of visible damage in transformed lines following chlorsulfuron applications, irrespective of the number of gene copies, indicated that the introduced genes were being expressed under field conditions. Although the transformed lines did not retain the yield performance of the parental cultivar, this study clearly established that resistance to chlorsulfuron was sufficient to protect the potato crop from the recommended field application rate of chlorsulfuron.

Table 2. Total table potato tuber yield (t/ha). Contrast between untransformed and transformed lines.

	Unsprayed	Hand weeded	Chlorsulfuron applications	
			1	2
Untransformed	68.1	62.8	30.1	4.8
SCI 1	32.5	33.9	45.5	39.0
SCI 2	43.5	38.0	40.5*	51.1
SCI 4	50.7	57.5^{ns}	45.9	40.9

Significant contrasts between untransformed and SCI lines. All contrasts significant at $p<0.01$, except *($p<0.05$) and ns (non significant).

The scale of the field evaluation of genetically modified potato lines was significant and allowed for an effective analysis of the performance of transformed plants in an appropriate agronomic situation. This is in contrast with the small scale of previous field evaluation studies with crop species that have been genetically modified for herbicide resistance (2). Although the transformed lines field tested in this study were indistinguishable from the parent cultivar in small scale field trials, these lines did not retain yield performance when trialled under the more rigorous experimental plot design and statistical analysis possible with larger scale field trials. This emphasises the need to produce a large number of independently selected transformed lines in the laboratory in order to recover lines with appropriate expression of the inserted genes, while maintaining the phenotype and yield performance of the parental cultivars.

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ENHANCEMENT OF CYTOCHROME P-450 MEDIATED ARYL HYDROXYLATION OF BENTAZON IN RICE MICROSOMES

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Summary. Bentazon 6-hydroxylase (B6H) activity was determined in rice microsomes to study methods of enhancing cytochrome P-450 mediated aryl hydroxylation of bentazon by hydroxylase inducing compounds. Pretreating rice seeds with 1,8-naphthalic anhydride (0.5-2%) and fenclorim (8-12 uM) increased B6H activity. Treatments of rice seedlings with ethanol (2.5%) and phenobarbital (12 mM) enhanced B6H activity, also. Five-day-old rice seedlings showed higher B6H activity which decreased with seedling age.

INTRODUCTION

Cytochrome P-450 enzymes catalyze the oxygenation of many chemicals including herbicides. The most important metabolic reactions of herbicides that are mediated by cytochrome P-450 include hydroxylation and dealkylation.

Bentazon tolerance among crop species is due to detoxification of the herbicide via aryl hydroxylation and subsequent glycosyl conjugation (10). The aryl hydroxylation of bentazon that occurs in bentazon-tolerant species is thought to be catalyzed by a cytochrome P-450 monooxygenase. The NADPH dependence and the inhibitor sensitivity of the reaction suggested the involvement of a cytochrome P-450. McFadden *et al.*(9) suggested that in addition to its NADPH-dependence, the aryl hydroxylation of bentazon by corn microsomes is catalyzed by a cytochrome P-450 monooxygenase which requires oxygen and is strongly inhibited by pretreatment with carbon monoxide and tetcyclacis, a potent inhibitor of plant cytochrome P-450 enzymes.

Significant rates of bentazon hydroxylation has not been demonstrable in microsomal fractions from noninduced seedlings because of low levels of cytochrome P-450s in plants and the lability of this enzyme system during isolation (12). Gronwald (6) suggested that safeners confer crop protection by causing the induction of enzymes catalyzing herbicide detoxification. There is indirect evidence which suggests that pretreatment with the safener naphthalic anhydride increases the activity of monooxygenases catalyzing herbicide metabolism (2, 13). Microsomal fractions isolated from naphthalic anhydride-treated maize and sorghum shoots catalyzed the *in vitro* aryl hydroxylation of bentazon by a cytochrome P-450 (3,9).

Little work has been done concerning cytochrome P-450 responsible for aryl hydroxylation of bentazon in rice. Up to now, no demonstration of this type of reaction in an *in vitro* system of rice has been published.

We have tested several chemicals known to induce cytochrome P-450 monooxygenases in various crops to determine if they will induce B6H in rice.

METHODS

Rice (*Oryza sativa* L.) seeds were germinated and grown in rolled germination paper moistened with 1 mM Ca_2SO_4 solution for 6 days in the dark at 25°C.

1,8-naphthalic anhydride (NA) and fenclorim (CGA 123407; 4,6-dichloro-2-phenyl-pyrimidine) were applied directly as seed dressings. Ethanol and phenobarbital were applied by incubating 5-day-old seedlings in 0.5-liter Erlenmyer flasks in shaking water bath for 24 hr before shoot tissues were excised. B6H activity was also measured with microsomes from 4 - 14-day-old rice seedlings to test the influence of seedling age on B6H activity.

Microsome Isolation: Etiolated shoots of 6-day-old seedlings were excised and ground (using an ice-cold mortar and pestle) in 2 ml /g fresh weight of chilled 0.1 M sodium phosphate buffer (NaPi), pH 8, that contained 40 mM ascorbate, 14 mM 2-mercaptoethanol, and 10 mM EDTA. The homogenate was filtered through cheese cloth and centrifuged at 20,000*g* for 20 min. The supernatant was then centrifuged at 100,000*g* for 90 min. The microsomal pellet was resuspended in 0.1 M NaPi, pH 8.

Hydroxylase assay. Assays contained 0.1 M NaPi, pH 8, 1 mM NADPH, 1 mg microsomal protein, 25 uM ^{14}C-bentazon (13.9 uCi/umol) in 500 ul total volume and were conducted for 45 min at 30 C. Assays were initiated by addition of NADPH and terminated by addition of 50 ul 4N HCL, and 25 ul MeOH. The reaction was terminated by adding 75 ul of cold stop solution which was a mixture of 4N HCL and methanol (2:1).

Extraction and analysis. The terminated assays were extracted twice with 1 ml ethyl acetate; fractions were combined, dried under N_2 gas, and redissolved in 100% MeOH. Products were separated using HPLC (C_{18} column, 35% CH_3CHN/65% H_2O, 1 ml/min flow rate) and quantified with a radioactivity flow detector.

Each treatment was replicated three times and all experiments were conducted twice.

RESULTS AND DISCUSSION

Pretreatment of rice seeds with NA at 0.5 to 2.0% greatly increased microsomal B6H activity as compared to untreated seedling microsomes, in which the activity was barely detectable (Fig. 1). Pretreating rice seeds with NA at 2% caused a 19-fold increase in the *in vitro* activity of the P-450 catalyzing the aryl hydroxylation of bentazon. At a concentration of 0.5% (w/w), NA did not inhibit growth of rice seedling but higher concentrations greatly inhibited seedling growth. McFadden et al.(9) reported that there was a significant increase in metabolism of bentazon in naphthalic anhydride-treated corn tissue with only a small increase in total P-450 content. They suggested that naphthalic anhydride may act by increasing the level of a specific isozyme(s) in corn shoots responsible for bentazon metabolism and may also have other effects in vivo which serve to stabilize enzyme activity during isolation. Burton and Manness (3) suggested that NA treatment induces isozymes with a higher affinity for bentazon, as evidenced in the lower Km from NA-treated microsomal preparations. Alternatively, NA might stabilize or activate the constitutive P-450 during the extraction and preparation of microsomes.

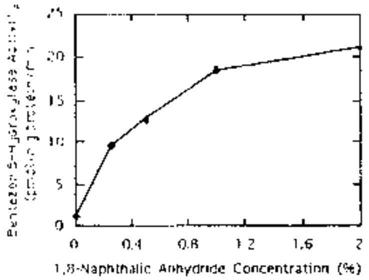

Fig. 1. Effect of 1,8-naphthalic anhydride on bentazon 6-hydroxylase activity in rice shoot microsomes.

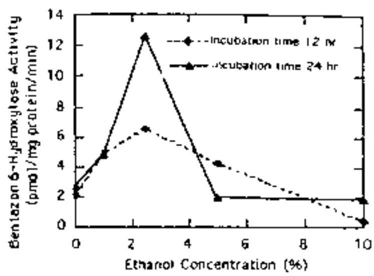

Fig. 2. Effect of ethanol on bentazon 6-hydroxylase activity in rice shoot microsomes.

As shown in Fig. 2, treatment of rice seedlings with ethanol 2.5% enhanced B6H activity (6.0-fold). Diclofop hydroxylase activity was increased 16-fold when wheat seedling tissues were treated with 10% ethanol (5). Hendry and Jones (8) also reported that 10% ethanol cause a 3-fold rise in cytochrome P-450 in intact mungbean.

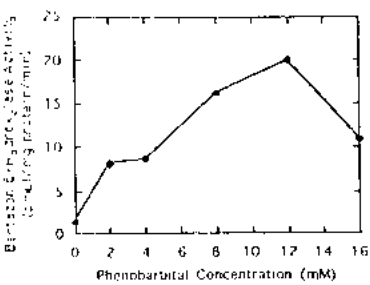

Fig. 3. Effect of phenobarbital on bentazon 6-hydroxylase activity in rice shoot microsomes.

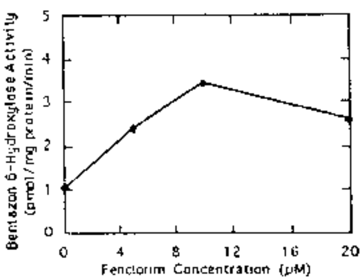

Fig. 4. Effect of fenclorim on bentazon 6-hydroxylase activity in rice shoot microsomes.

When rice seedlings were treated with phenobarbital at 12 mM, B6H activity was increased 13.1 times (Fig. 3). It is widely known that pretreating mammalian tissues with phenobarbital increases cytochrome P-450 levels and the rate of metabolism of selected xenobiotics because of the ability of phenobarbital to induce cytochrome P-450 isozymes (1, 11). Zimmerlin and Durst (14) reported that diclofop hydroxylase and cytochrome P-450 levels were increased 15.6- and 1.8-fold, respectively, when wheat seedlings were treated for 48 hr with 8 mM phenobarbital. Fonne-Pfister et al.(4) also reported monooxygenase induction in Jerusalem artichoke tissues treated with phenobarbital and clofibrate.

Induction of B6H activity by fenclorim at 8 to 12 uM was observed, but induction was not as effective as NA, ethanol, and phenobarbital (Fig. 4).

When microsomes were extracted from shoots of 4 to 14-day-old seedlings to test B6H activity at different seedling ages, B6H activity was highest in 5-day-old seedlings and then decreased as the age of the seedling tissues increased (Fig. 5). Hendry et al.(7) reported that constitutive cytochrome P-450 concentrations in mungbean microsomes decreased rapidly with age.

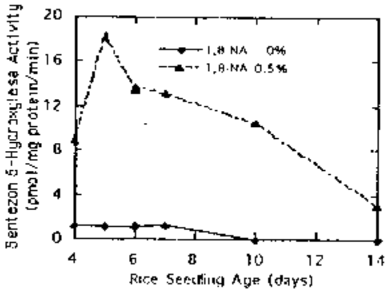

Fig. 5. Effect of seedling age on bentazon 6 hydroxylase activity in microsomes from 1,8 naphthalic anhydride treated and untreated rice shoots.

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RESPONSE AND ACETOLACTATE SYNTHASE ACTIVITY IN DIFFERENT RICE CULTIVARS (ORYZA SATIVA L.) TO CINOSULFURON

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Summary. Acetolactate synthase (ALS) activity was determined in germinating seedlings of two rice cultivars treated with cinosulfuron [3-(4,6-dimethoxy-1,3,5-triazin-2-yl)-1-[2-methoxyethoxy)-phenylsulfonyl]-urea]. IR 74 (Indica type) was more tolerant than Hwajinbyeo (Japonica type) under various rates of cinosulfuron applied at the pregermination stage. *In vitro* response of ALS activity in the two rice cultivars was similar to I_{50} values (cinosulfuron concentration required for 50% inhibition of ALS activity) of about 23 ppb. *In vivo*, ALS activity of IR 74 increased as the seedlings grew, but that of Hwajinbyeo dropped at 5 days after 10 ppm cinosulfuron treatment and shoot growth of Hwajinbyeo lagged at 4 to 5 days after herbicide treatment. ALS activity and shoot growth of Hwajinbyeo was resumed from cinosulfuron-induced inhibition at 6 days after cinosulfuron treatment. The differential response of ALS activity in two different rice cultivars against cinosulfuron may not be due to difference of ALS sensitivity, but rather due to different metabolic inactivation rates of cinosulfuron.

INTRODUCTION

The sulfonylurea herbicides are known to inhibit the activity of acetolactate synthase (ALS), a key enzyme in the biosynthesis of branched chain amino acids (BAAs), valine, isoleucine and leucine (10, 18). Chlorsulfuron, one of the sulfonylurea herbicides, selectively inhibits the cell cycle in root tips without apparently affecting any other metabolic process. It was suggested that chlorsulfuron inhibits cell cycle progression by blocking the G2 into mitosis and G1 into S phase through inhibition of cell cycle specific RNA synthesis (13). However, the inhibitory effect of cell cycle can be blocked or reversed by adding BAAs to the culture medium. Further, Rost *et al.* (1990) proposed that the plant cell cycle progression was not blocked by the reduction of BAAs pool in itself, but a toxic intermediate, such as α-amino-*n*-butyrate (11), α-ketobutyrate (5), or some other intermediates probably might inhibit the cell cycle specific protein, and thereby plant cell division and growth would be inhibited. Accumulation of α-ketobutyrate caused by inhibition of the progression of the BAAs biosynthesis can partially mediate the herbicidal activity of ALS inhibitors (5).

The selective action of sulfonylurea herbicides between crops and weed plants can be attributed to the rapid metabolism of the herbicides to inactive products in crop species (15). On the other hand, their resistance was assumed to involve the reduction of ALS sensitivity (14). Exceptionally, annual ryegrass (*Lolium rigidum*) has a wheat-like detoxification system (3). The resistance mechanism of mutants induced is based on one or two base pair substitution of ALS gene resulting in various forms of less sensitive ALS enzyme (6). Cinosulfuron is a sulfonylurea herbicide used for the control of broadleaf weeds and annual and perennial sedges in rice (9). Slight phytotoxicity in rice caused by cinosulfuron can be safed by dymron [1-(α,α-dimethylbenzyl)-3-p-tolyl urea] application, showing a safening effect (2). This study was conducted to determine the effect of cinosulfuron on the growth response and ALS activity of two rice cultivars, and the effect of BAAs on cinosulfuron inhibition.

MATERIALS AND METHODS

Rice cultivars: Hwajinbyeo was provided by the Kyungpook Provincial Rural Development Administration, Taegu, Korea and IR 74 from IRRI. These cultivars were chosen as the plant materials because they have shown differential response to cinosulfuron in our preliminary test. The technical grade of cinosulfuron was provided by Kyungnong Corperation Ltd, Seoul, Korea. Cinosulfuron was dissolved in dimethyl sulfoxide and diluted with distilled water to the desired concentrations. The concentration of dimethyl sulfoxide was maintained within 0.2% in solutions.

Effect of cinosulfuron on the growth of rice seedlings. Seeds of two rice cultivars were imbibed at 30°C for 20 h in the dark and pregerminated in the incubator maintained at 30°C in the dark. Pregerminated seeds were transferred into plastic petri dishes containing 10 mL of various concentrations of cinosulfuron and maintained at 30°C in the dark. Growth of shoot and root was determined at 7 days after herbicide application. The experiment was conducted three times with two replications. The data presented are the means of all experiments. The herbicide concentrations (GR_{50} values) at which 50% of plant growth was inhibited as compared to the untreated control were calculated from the data by plotting them on log normal paper, determining where the graph intersected the 50% line.

Effect of valine, leucine and isoleucine on cinosulfuron inhibition. Pregerminated seeds were placed in petri dishes containing 10 ppm cinosulfuron without or with 1 mM each of valine, leucine and isoleucine and petri dishes were maintained at 30°C in the dark. The seedlings were harvested and separated into shoot and root after 7-day incubation and dry weights of each part were measured after drying at 70°C for 3 days. This test was conducted three times with two replications.

Acetolactate synthase activities of two rice cultivars affected by cinosulfuron. Two cultivars were grown under the condition as discribed in experiment I. Shoot tissues were harvested at the 3, 4, 5, 7 days after herbicide application for *in vivo* ALS activity. For *in vitro* ALS activity, the shoot of 4-day old seedlings grown in the herbicide-free solution was harvested. ALS was extracted as described by Ray (10) with 100 mM potassium phosphate (pH 7.5) buffer. ALS activity was assayed as previously outlined by Singh *et al.* (17). The decarboxylated acetoin was quantified by the method of Westerfeld (19). The absorbance of the solution was measured at 525 nm. Protein was determined according to the method of Bradford (1) using bovine serum albumin as the standard. Each assay was run in duplicate and the experiments were repeated three times.

RESULTS AND DISCUSSION

Growth of rice seedlings affected by cinosulfuron. The shoot and seminal root growth of Hwajinbyeo was more inhibited by cinosulfuron treatment in pregerminated seeds for 7 days at the all rates than those of IR 74 (Fig. 1). The concentrations required for 50% inhibition of the shoot growth, as compared to the untreated control, were about 6 ppm for Hwajinbyeo and above 100 ppm for IR 74, respectively. Fifty % inhibition of the seminal root elongation (GR_{50} values) was made at 0.5 ppm for Hwajinbyeo and 10 ppm for IR 74. However, in terms of dry weight of two rice cultivars, degree of growth inhibition of Hwajinbyeo was much greater than that of IR 74. Three ppm cinosulfuron inhibited 50% of shoot growth of Hwajinbyeo, but IR 74 was inhibited only 40% at 100 ppm cinosulfuron. The similar trend of rice cultivar response to sulfonylurea herbicides was confirmed by other researchers (8, 20). Yuyama *et al.* (1983) suggested that Japonica type rice cultivars were generally more sensitive to bensulfuron methyl than rice cultivars of Indica type in field test. Ohno *et al.* (1986) also reported the similar observation, and the differential response among the different ecogeographic races resulted from the difference of translocation, degradation in roots and metabolic inactivation of bensulfuron methyl (7).

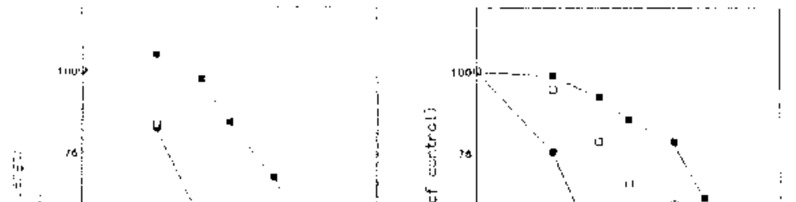

Figure 1. The effect of cinosulfuron on the growth of the rice cultivars. The cinosulfuron was treated with various concentrations at germinated seeds. Shoot and root elongation (A) and dry weight (B) were measured after 7 d growth. ■ -- ■; shoot of IR 74, □ -- □; root of IR 74, ● -- ●; shoot of Hwajinbyeo, ○ -- ○; root of Hwajinbyeo.

Effect of valine, leucine and isoleucine on cinosulfuron inhibition. The shoot and root growth of Hwajinbyeo treated with 10 ppm cinosulfuron in the absence of amino acids supplementation became 28.7% and 16.8% of the untreated control, whereas those of IR 74 applied with 10 ppm cinosulfuron without amino acids supplementation were 85.2% and 65.3% of herbicide-free cultured plant (Table 1). Ten ppm cinosulfuron containing the BAAs increased the shoot and root growth of Hwajinbyeo from 28.7% to 96.9% and 16.8% to 60.9% of the untreated one, while there was very small recovery in the shoot and root growth of IR 74, from 85.2% to 95% and 65.3% to 73.3%. Addition of 1 mM Val, Ile and Leu to 10 ppm cinosulfuron solution showed the marked recovery of the shoot growth inhibition by cinosulfuron in two rice cultivars, especially greater recovery in Hwajinbyeo, showing about 3.38-fold. However, root growth was partially recovered by the addition of BAAs.

Ray (1984) indirectly accounted for the site of action of chlorsulfuron in pea by the study of supplementation of amino acids where supplementation of Val and Ile was able to reverse the growth inhibition of pea root and seedlings caused by chlorsulfuron. The protective effect of BAAs supplementation on rice suspension-cultured cells treated with bensulfuron methyl was also observed by Sengnil *et al.* (1992). The fact that supplementation of Val, Ile and Leu ruled out cinosulfuron-induced growth inhibition indicates that the primary target site of cinosulfuron might be ALS.

Acetolactate synthase activity of two rice cultivars affected by cinosulfuron. The extractable levels of ALS from 4-day old seedlings of Hwajinbyeo and IR 74 were 5.7 µM and 6.4 µM acetoin/mg protein/h, respectively. The sensitivities of ALS to cinosulfuron under this assay condition were similar with I_{50} values (herbicide concentration required for 50% inhibition of ALS activity) of about 23 ppb (Fig. 2). The shoot growth of IR 74 in the presence of 10 ppm cinosulfuron showed a linear growth type, and after 7-day exposure the average shoot length of IR 74 was 84% of the untreated control. The extractable level of ALS from IR 74 grown under 10 ppm cinosulfuron increased as the shoot grew (Fig. 3). The shoot growth of Hwajinbyeo lagged at 3 to 5 days after treatment with 10 ppm cinosulfuron. After 7-day exposure to cinosulfuron, the average shoot length of Hwajinbyeo was 42.6% of the untreated control, showing 57.4% inhibition. The extractable level of ALS from Hwajinbyeo dropped at 5 days after cinosulfuron application (Fig. 4). The reduction of ALS activity at this stage may be related to retardation of the shoot growth of Hwajinbyeo. At 5 days after cinosulfuron exposure, ALS activity started to recover, and the shoot growth of Hwajinbyeo increased simultaneously. Although IR 74 was less inhibited by cinosulfuron and it had higher ALS content, there is no correlation between seedling growth and ALS content which can support tolerance of rice cultivars used in this study.

Table 1. Protective effect of Val, Leu and Ile on cinosulfuron inhibition of the growth of rice seedlings

Cultivars		Cinosulfuron conc. (ppm)	Amino acids[a] 0 mM		Amino acids[a] 1 mM	
			mg/plant			
Hwajinbyeo	Shoot	0	2.59	(100)[b]	2.42	(93.4)
		10	0.74	(28.7)	2.51	(96.9)
	Root	0	1.45	(100)	1.04	(71.7)
		10	0.24	(16.8)	0.88	(60.9)
IR 74	Shoot	0	3.77	(100)	3.76	(99.7)
		10	3.21	(85.2)	3.46	(95.0)
	Root	0	1.76	(100)	1.54	(87.5)
		10	1.15	(65.3)	1.29	(73.3)

[a] Amino acids such as Val, Leu and Ile were spontaneously treated with 10 ppm cinosulfuron to germinated seed.

[b] The values are given as the average dry weight of the two parts, the % of control are presented in parenthesis.

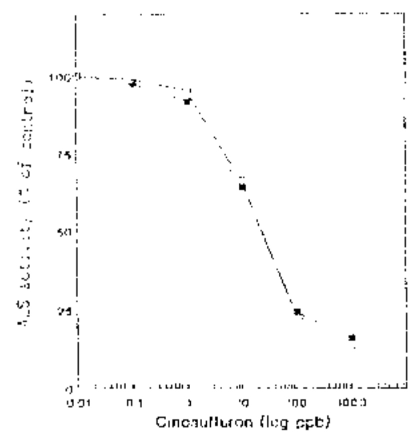

Figure 2. *In vitro* effects of cinosulfuron on ALS activity from 4 day-old seedlings of IR 74 (○) and Hwajinbyeo (■).

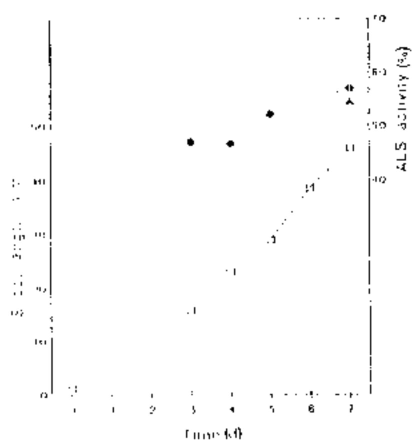

Figure 3. Shoot growth (□ -- □) and ALS activity (● -- ●) of IR 74 as affected by 10 ppm cinosulfuron. ▲: Shoot length of untreated control.

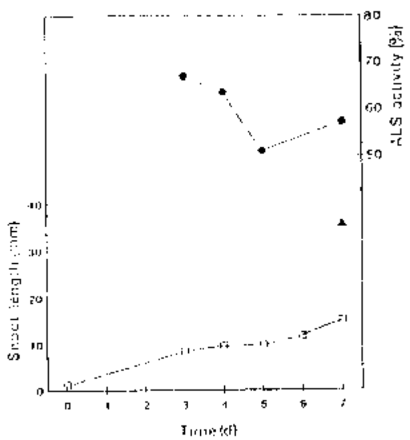

Figure 4. Shoot growth (□ -- □) and ALS activity (● -- ●) of Hwajinbyeo as affected by 10 ppm cinosulfuron. ▲: Shoot length of untreated control.

Very similar trend of ALS activities in the two rice cultivars against various concentrations of cinosulfuron was observed from the test of *in vitro* enzyme activity. This results suggests that higher tolerance of IR 74 to cinosulfuron may not be due to the cinosulfuron-insensitive ALS. Further it was previously suggested that sulfonylurea herbicide selectivity between crops and weeds may be caused by rapid metabolic inactivation in crop plant (15) and varied tolerance among crop cultivars might be resulted from difference in translocation and metabolism of herbicide (7). Inherent rice cultivar tolerance to bensulfuron methyl, one of sulfonylurea herbicides, resulted from the rapid metabolic inactivation, O-demethylation of the pyrimidine ring of bensulfuron methyl into herbicidally inactive 4-hydroxy-6-methoxy-pyrimidinyl derivative (7). The difference of *in vivo* ALS activity between Hwajinbyeo and IR 74 may be induced by differential metabolic rate, which resulted in difference of herbicide rates reached to the site of action and which may be responsible for differential response between two cultivars.

In this experiment, cinosulfuron was treated at pregerminated seed stage in which nutrients including amino acids can be translocated from seed to the developing shoot. Thus the inhibition of the biosynthesis of BAAs by cinosulfuron may not probably be the major cause of the retardation of rice seedling growth. It is assumed that different response of rice cultivars to cinosulfuron observed in this study will partially depend on other factors rather than ALS properties, such as the rate of herbicide metabolism in the plant cell, and the levels of enzymes capable of inactivating herbicide although they were not studied here.

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ALLELOPATHIC POTENTIAL OF BROOM (*SAROTHAMNUS SCOPARIUS*) DOMINATING POST-FIRE STANDS IN SOUTHWEST JAPAN

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Summary. The Seto Inland Sea region of southwest Japan has a relatively dry climate where forest fires frequently break out at the slopes. Broom, *Sarothamnus scoparius*, has been introduced into the area and dominates post-fire stands 3-4 years after establishment. Few seedlings of other plants grow in the community. Greenhouse experiments were carried out to clarify its allelopathic and shading effects.

Aqueous extracts of broom shoots inhibited growth of the seedling of *Pinus densiflora* which is usually dominant in secondary succession in this region, and in some cases stimulated growth of the seedlings of broom and *Festuca arundinacea*. Neither *P. densiflora* nor *Lespedeza bicolor* could survive under dense broom canopies due to allelopathy and shade stress. The shade tolerance of broom seedlings was quite low and they could not survive under broom canopy.

INTRODUCTION

The broom, *Sarothamnus scoparius* (L.) Wimm. ex koch, is a rhizobium nodulated leguminous shrub which grows up to 4 meters in height and is indigenous in Europe, North Africa and Western Asia (2). Its stem possesses the photosynthetic activity with few small leaves that often defoliate. Symbiotic nitrogen fixation makes it a fast and well growing species in unproductive poor soil areas (14), but it only dominated at an early stage of plant succession (15). Therefore, broom is considered desirable species where the aim of vegetation management is to revegetate by native species in this region (6,16).

The broom was introduced into Japan during 1670's and has been widely planted as a horticulture shrub (4). Recently it has also been utilized as a nurse species for afforestation of post-fire stands (5). The forest fire often occurs in Seto Inland Sea region in air dried early spring (7,8). The broom is seeded or planted for the quick revegetation of the site to protect from soil erosion. The introduced broom becomes dominant soon afterward (13), but seedlings of component species of secondary succession in this region such as *Lespedeza cyrtobotrya*, *Pinus densiflora* (8) scarcely appear beneath and around this shrub.

Since Cowles (1) emphasized the role of allelopathy in plant succession, numerous studies have been done in this field in the United States. In Japan the role of allelopathic agents which are extracted from the dominant species in secondary succession was pointed out (11). There is a possibility that allelopathic agents are responsible for the introduced broom dominating sites in Seto Inland Sea region (3). However, allelopathic phenomena of broom plant has not been reported in the other regions of Japan. Therefore, if allelopathic agents take parts in the phenomena of Seto Inland Sea region, the specific conditions promoting effectiveness of this agents after egression from broom must exist.

The experiments reported here were performed to test the hypothesis that the specific conditions of Seto Inland Sea region promote the effect of allelopathic agents from the broom. Inhibitory effects of the extract from the broom on seedlings of *Lespedeza cyrtobotrya*, *Pinus densiflora* and the broom were tested under shaded and full-light conditions.

METHODS

The result of bioassays using the aqueous extracts from the broom indicated that its stem with leaf (SWL) inhibited remarkably the growth of lettuce seedlings both radicle and hypocotyl (Table 1). On the basis of this fact, the inhibitory effect of SWL was tested in this study.

Table 1. The growth inhibition of radicle and hypocotyl of lettuce plant by aqueous extracts of broom (redrawn from Nemoto *et al.* 1988)

	Radicle length (mm)	Hypocotyl length (mm)
Stem with leaf (SWL)	5.3 ± 1.0*	6.7 ± 1.6
Root	10.5 ± 2.3	8.8 ± 1.9
Control	21.4 ± 3.3	8.6 ± 1.9

* mean ± s.d.

Test with fragments of SWL. The fragments of SWL of both broom and *Lespedeza cyrtobotrya*, indigenous leguminosae in Far East including Seto Inland Sea region which was possessed of non-allelopathic effect, were used in this experiment. SWL of both species were dried at 70°C for 48 hours and broken into fragments, then, 10 g, 20 g, 30 g and 40 g of the fragments of broom SWL were mixed up with 40 g, 30 g, 20 g and 10 g of that of *L. cyrtobotrya* respectively. Total weight adjusted on 40 g among 4 series. Pots 15 cm in diameter, 10 cm in depth were filled with granitic gravel. The fragment mixture was mixed with the gravel of upper one-third of the pot. Seedlings of *Pinus densiflora*, *L. cyrtobotrya* and the broom were used for receptor plants. At 18 days after seeding, germinated seedlings of these species were transplanted into pots. Three seedlings were set in each pot and each treatment was done in three replicates. The pots were placed in a greenhouse where the room temperature was maintained at 25°C.

Test with aqueous extracts of SWL. The broom SWL kept in semi-dried cold room (5°C) was used. 2 L of distilled water was added to 100 g of broom SWL at about 45°C. After 1 h, the aqueous extract was filtered through a 1.2 mm sieve. *Lactuca scariola* L. var. sativa Bisch (lettuce), *Pinus densiflora* Sieb. et Zucc., *Pinus thunbergii* Parl., *Lespedeza bicolor* Turcz. var. japonica Nakai, *Miscanthus sinensis* Anderss, *Artemisia princeps* Pampan., *Trifolium pratense* L. (L.) Wimm. ex Koch, *Dactylis glomerata* L., *Festuca arundinacea* Schreb were used as receptor plants. The last three species were commonly introduced for recovery of post-fire stands (5). The seedlings of receptor plants or 20 days after emergence, except for lettuce, were transplanted in 1/5000 a Wagner pots filled with Masa. This material originated from the weathered granite and is the same parent material of soil as Seto Island Sea region. The lettuce were directly seeded. 500 ml of aqueous extract was added to each plot with three treatments. Seven plants were cultivated per pot with two replications. The pots were placed in a greenhouse where the temperature was maintained at 20°C.

Evaluation of complex effects of aqueous extract and shading. To evaluate the complex effects of aqueous extract and shading, *P. densiflora*, *L. bicolor* and *S. scoparius* were used for receptor plants. Thirty individuals for each of these species were seeded in 1/5000 a Wagner pots filled with the same soil as test 2 in 21 September 1988 and the pots were placed under dim condition (relative light intensity was reduced to 5.8% by cheese cloth cover) for about 150 days (13 February 1989). Up to two weeks after seeded, germination percentage of these species increased over 90%. 2.4 L of distilled water was added to 100 g of the broom SWL which is same one as test two at 45°C (high concentration of aqueous extracts). The EC value of this extracts was lower than 1 mS/cm. Then this extract was diluted to one half with distilled water (low concentration). 500 ml per pot of these two levels of extracts were employed every times. At the same time 500 ml of distilled water were added to control pots. The aqueous extracts were added five times (2, 6 Dec. 19, 23 and 30 Jan.) to receptor plants. This series of test was done with two replicates. Masa soil of this study was collected at Takahagi-City, Ibaraki Prefecture, and the broom was cultivated at the experimental farm of National Institute of Agro-Environmental Sciences. Seeds of *P. densiflora*, *P. thunbergii* and *L. bicolor* were presented from Forestry and Forest Products Research Institute. Seed of *M. sinensis* was presented from The Japan Association for Advancement of Phyto-Regulators. Other seeds were bought on the market. Seeds of leguminous species (*C. scoparius* and *L. bicolor*) were treated by sulfuric acid to break the dormancy before seeding.

RESULTS

Effects of broom SWL on the growth of seedlings of receptor plants. The seedlings of *P. densiflora* transplanted in the pots were extremely inhibited in the test with SWL fragments of the broom. Individuals withering above-ground part appeared soon afterward and all individuals in the pot that contained 40 g of the SWL died within 2 weeks after transplanting. The number of dead individual increased with increasing the amount of the fragments of broom (Fig. 1). At two months after transplanting, the growth of above-ground part did not show the definite tendency, while the biomass of subterranean part decreased with increasing the amount of SWL fragment.

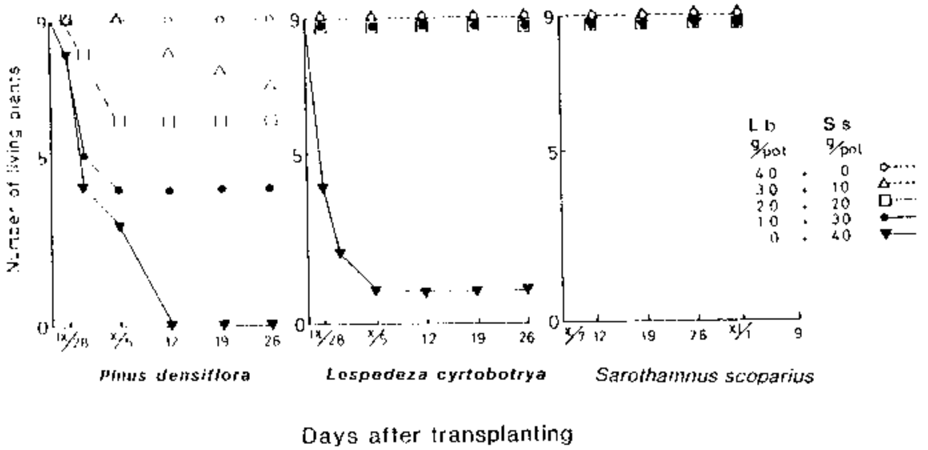

Figure 1. Survivorship curve of the seedlings of *P. densiflora*, *L. cyrtobotrya* and *S. scoparius* which were cultivated the pots containing the SLW fragments both broom and *L. bicolor*.

Soon after transplanting, the growth of *L. cyrtobotrya* was depressed where a lot of SWL treated, and only one individual survived in the pot that had 40 g of SWL added (the largest amount of application). However, 3 weeks after transplanting the growth vigor had recovered in 20 g pot. The dry matter production of both above-ground and subterranean became the largest level in the 20 g pot 2 months after treatment.

Broom did not die in all treatments. In 20 g plot total dry weight of broom plant 2 months after treatment had also became the largest value, and subterranean weights in 0 g and 10 g pot were apparently smaller than that in the other treatments. The effects of SWL fragment on the seedling growth of above mentioned three species were quite varied. Then 10 species were employed for receptor plants to classify the effects of the aqueous extracts of broom SWL on the seedling growth. The sensitivity of seedlings of 10 species employed were divided into three categories, 1 : the biomass decreased with increasing the amount of extracts, 2 : individual biomass at one time application pot is over that at control, and 3 : individual biomass at control pot is the smallest level in the whole. At first *P. thunbergii*, *T. pratense* and *L. scariola* were sensitive to the broom extracts and were involved in the first category. Secondary *P. densiflora*, *L. bicolor* and *M. sinensis* were involved in the other category. By contrast, species involved in the third category such as broom, *F. arundinacea*, *D. glomerata* and *A. vulgris* were rather promoted by the application of this extract. The sensitive species to broom extracts showed a tendency to become inhibited in their root development. As a result their T/R ratio of individuals in the extract treated pots were higher than that in the control. By contrast, the T/R ratio of broom decreased with increasing the frequency of extract application.

Complex effects of broom extract and shading. *P. densiflora* and *L. bicolor*, which are early colonizers after forest fire, and introduced broom are sun demanded plant. Therefore their seedling growth under dense shrub of broom may possibly be inhibited by shade stress.

When the broom extract was added to seedlings of *P. densiflora*, *L. bicolor* and broom, which were cultivated 2 months under shade condition (RLI=5.8%), withered individuals arised in both species. The greatest number of dead individuals was broom seedlings. Then the seedlings of *P. densiflora* followed. This tendency differed much from that showing the above-mentioned test one.

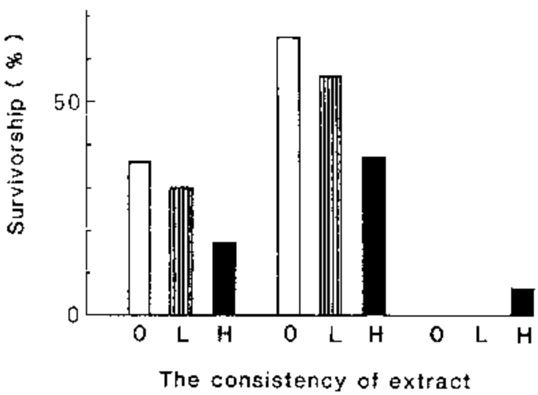

Figure 2. The relation between the survival rate of receptor plants and consistency of broom extracts under shade condition after 5 times application of these extracts 0 : control, L : low concentration, H : high concentration

Figure 2 shows the relationship between the consistency of extract and survival rate after 5 times application of these extract. The survival rate of *P. densiflora* and *L. bicolor* applied with the thicker extract was lower than that applied with the thinner extract. While the survival rate of broom showed reversed tendency. Seedlings of *P. densiflora* were cultivated under full-light condition and then broom extract was added in pots the same way as mentioned above. In this case one seedling died in thick extract application pot.

DISCUSSION

In Seto Inland Sea region artificial broom shrubs planted at post fire stands where the parent rock is granite inhibit the growth of regenerated coppices and seedlings originated from soil seed bank (9). Allelopathic agent after egression from broom plant was pointed out to take part in a factor of this inhibitory action.

Specific difference of the sensitivity to allelopathic agent. Results of the experiment using aqueous extracts of various kind of organs of broom plant indicated that SWL apparently inhibited the radicle growth of lettuce (10). So broom SWL was entirely employed in this study.

The sensitivity of receptor plant to the fragment of broom SWL differed with species : *P. densiflora* and *L. cyrtobotrya* were relatively sensitive, while *S. scoparius* and *Artemisia princeps* were non-sensitive. However, the growth of broom sensitive species above-mentioned were not influenced by the SWL of *L. bicolor*, which is a abundant shrub at young post-fire stand.

In the field condition allelopathic agent contained in broom SWL is leached by rain and accumulate in soil under broom canopy. Therefore, method using aqueous extracts of broom SWL may reflect more the field condition than the addition method with SWL fragment. The result of the test with aqueous extracts of broom indicates that the response of receptor plants differed with species in growth. One is promoted and the other is suppressed. Therefore, it may well be that allelopathic agents take part in interspecific relation of plant community in post-fire stands.

Complex effects of allelopathic agent and shading by broom dominated. Broom canopy completely covered the ground surface when artificial broom shrub at post-fire stands developed into prosperous stage (13). Early colonizers of sun demanded plants must be exposed under such light condition. In general, the root growth is suppressed and the T/R ratio is increased under shade condition. The allelopathic agent of broom suppressed particularly the subterranean organs of sensitive receptor plants. So root of the broom sensitive *P. densiflora* and *L. bicolor* as sun demanded plants are complexly damaged by both effects in the soil under broom canopy and withered individuals will frequently occur. The same phenomenon was observed in the seedlings of *Cryptomeria japonica* in nurseries maintained under shade condition. The number of witherd individuals of *C. japonica* increased with increasing the amount of fertilizer (12). By contrast, seedlings of *P. densiflora* cultivated under unshaded condition were scarcely influenced by the effect of allelopathic agent of broom.

Allelopathic agent of broom SWL accelerates seedling growth of broom. Under dense broom canopy, however, there are very few individuals except for the existence of first year seedlings. This fact indicates that broom seedling is extremly weak in shade condition and does not survive under dense broom canopy. Shade tolerance of broom is less than those of *P. densiflora* and *L. bicolor* as sun demanded plants. But the proper amount of allelopathic substance of broom SWL may raise the survival rate of its seedling under shading condition (Fig. 2). The floristic composition and vegetation succession in Seto Island Sea region may well be partially modified by allelopathies of introduced broom.

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ALLELOPATHIC POTENTIAL OF *EUPATORIUM ODORATUM* IN ABANDONED SHIFTING CULTIVATION FIELDS IN TROPICAL ASIA

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Summary. The perennial weed *Eupatorium odoratum* invades rapidly into and dominates in abandoned shifting cultivation fields in tropical Asia. The effects of leaf and stem exudates of *E. odoratum* on the germination and growth of the common weeds such as *Crassocephalum crepidioides, Ageratum conyzoides, Cynodon dactylon, Oxalis corniculata* and *E. odoratum* were studied. Aqueous leaf extracts delayed germination of all the weeds in petri dishes. Exudates from powdered leaf and stem inhibited seedling growth of all the weeds in pot culture in the greenhouse. The growth of *C. crepidioides*, the first dominant in such fields, was inhibited more than that of the other three species. Combining effects of allelopathy and shading gave greater inhibition than either factor alone on all the weeds except for *C. dactylon*, which was unaffected by the leaf exudates.

INTRODUCTION

Eupatorium odoratum is a perennial weed in crop field and pasture of southern Asia and western Africa (4). In abandoned shifting cultivation fields in northeast Thailand, *Crassocephalum crepidioides* is the first dominant species and is followed by *Ageratum conyzoides* in the early stage of the first year. After that, the most dominant species changes to *E. odoratum* in the later stage of the same year, and its dominance increases in the next year. *E. odoratum* is able to grow quickly and forms a tangled bush of 3 to 7 m in height (6, 7, 8).

It is reported that the *E. odoratum* seedling population experienced very heavy mortality with only 1.4% survivors left at the end of one year after germination (9). The occurrence of seedlings of the other species at the neighbourhood where *E. odoratum* is growing is also a few. These phenomena may be due to the allelopathic substances produced by *E. odoratum* plants, as well as the competition with *E. odoratum* plants for water, nutrient, light etc. (7).

As the bush of *E. odoratum* develops, the sunlight rarely reaches to the ground surface of its community. The percentage to full sunlight at the ground surface of its community is only about 10%. For that reason, there are a possibility of combining effects of allelopathy and shading on the growth of weeds in the field conditions.

The objective of this study is to determine the allelopathic effect of *E. odoratum* on seed germination and seedling growth and to evaluatethe combined effects of allelopathy and shading on seedling growth of weeds.

MATERIALS AND METHODS

To study the allelopathic potential of *E. odoratum*, five common weeds in the abandoned shifting cultivation field in northeast Thailand, i.e., *Crassocephalum crepidioides, Ageratum conyzoides, Cynodon dactylon, Oxalis corniculata* and *E. odoratum* were selected as the receptor species.

Germination test. Aqueous extract was made from fresh leaf of *E. odoratum*. The fresh leaf was cut into 2 cm fragments and soaked in 500 mL distilled water at 4°C. After 3 days, the aqueous extract was filtered, and the filtrate was diluted below 1 mS/cm in electroconductivity (2). The germination test was carried out in 9 cm glass petri dish on two layers of filter paper wetted with 4 mL of the extract. Twenty-five seeds were evenly dispersed in each dish. The control was treated with distilled water instead of the aqueous extract. The dishes were incubated at 25°C by day and 20°C at night. The germination percentage was observed every day during ten days. This test was replicated twice.

Pot experiment. The washed quartz sand was put into unglazed pots (12 cm diameter), and three seedlings of receptor species were transplanted in each pot. This experiment was conducted in three pots for each species. After one week, powdered dead leaf, fresh leaf and stem of the *E. odoratum* plants were placed on the quartz sand. Each pot was watered daily and plant height was measured every five days. After three weeks, all plants were harvested, and root length, leaf area, and dry weight were measured. As control, powdered humus made from the common forest plants, which has no allelopathic effect, was used instead of the plant powder of *E. odoratum*. The amounts of dead leaf, fresh leaf and stem used in the experiment were 8.9 g, 9.1 g and 6 g, respectively, and that of humus for the control was 6 g (these contain the equal amount of nitrogen). Prior to transplanting, the seedlings of each species were germinated and grown for one month in soil and vermiculite mixture in the greenhouse.

Combined effects of allelopathy and shading. The same pot experiment as mentioned above was conducted under shading condition in a shadow box. Fresh leaf powder was used in the test pot, and humus powder was used in the control pot. Full sunlight and two shading conditions (the percentages to full sunlight were 30% and 10%) were set. The test and control pots were put under these conditions just after the two kinds powder were placed on the quartz sand. Each pot was watered daily and the plant height was measured every five days. After three weeks, all plants were harvested and the root length, leaf area and dry weight were measured.

RESULTS AND DISCUSSION

The germination of all the weeds in petri dishes were delayed from two to four days by the aqueous leaf extract of *E. odoratum*. The germination of weeds on the 10th day after the treatment was about 80% of the control (Fig. 1). In the pot experiment, the seedling growth of all receptor plants was reduced when the powdered dead leaf, fresh leaf and stem were placed on the sand surface. The powdered dead leaf exhibited remarkable growth inhibition. By the treatment of dead leaf, dry weight of all the weeds were reduced by 14 to 44% of the control (Fig. 2). The growth of *C. crepidioides* was inhibited more than that of the other species, on the other hand *A. conyzoides* and *C. dactylon* were less affected. These results demonstrated that *E. odoratum*, especially its dead leaf, had allelopathic potential and its effects were different between the receptor species. The fact that *C. crepidioides*, the first dominant species in abandoned shifting cultivation fields, was most inhibited by *E. odoratum* indicates that *E. odoratum* will become the most dominant species in the common Thailand forests, even if *C. crepidioides* is the first dominant species. It was reported that the essential oil of *E. odoratum* had an anti-bacterial activity, and its components were identified (5). However, allelopathic substances of *E. odoratum* are not yet determined.

The inhibitory effect of exudate from powdered leaf on the receptor species was enhanced by shading, and the inhibition got greater with higher shading level (Figs. 3 and 4). *C. dactylon* looked unaffected by the leaf exudate under shaded condition. This indicates that *C. dactylon* was so sensitive to shade that the effects of exudates appeared ineligible. Incidentally, the relative light intensity at the ground surface in *E. odoratum* community was about 10%; seedlings in this experiment were placed in the similar dark conditions.

In the field, the combined effects of allelopathy and shading may inhibit seedling growth; moreover if competitive and environmental stresses are added, ultimately these seedlings may exhibit low survivorship. It was reported that the effects and amount of allelopathic substances released by plants were different among environmental conditions (1, 3). Therefore it is very important to consider the combining effects of allelopathy and environmental stresses under field conditions.

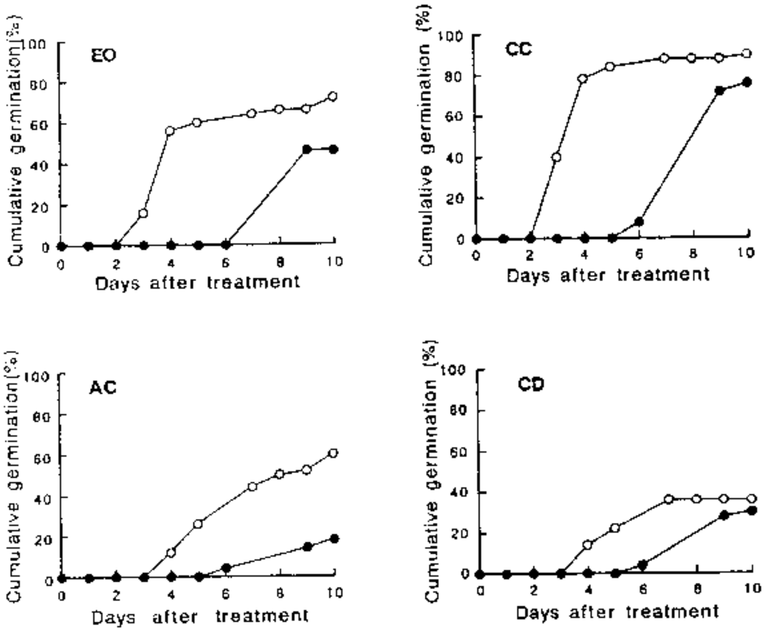

Figure 1. Effect of aqueous leaf extract of *E. odoratum* on the receptor plants on the seed germination. EO: *E. odoratum*, CC: *C. crepidioides*, AC: *A. conyzoides* and CD: *C. dactylon*. ○ : control (distilled water), ●: leaf extract.

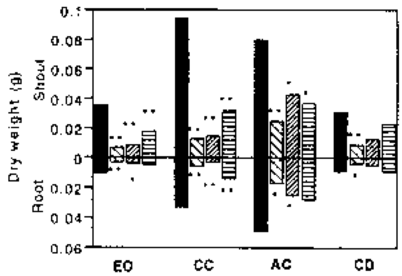

Figure 2. Dry weight of the receptor plants grown in the pots at different treatments. EO: *E. odoratum* , CC: *C. crepidioides* , AC: *A. conyzoides* and CD: *C. dactylon* . ■: control ▧: dead leaf ▨: fresh leaf ▤: stem. * : significant at 5% level and ** : 1% level (Man-Whitney's U-test).

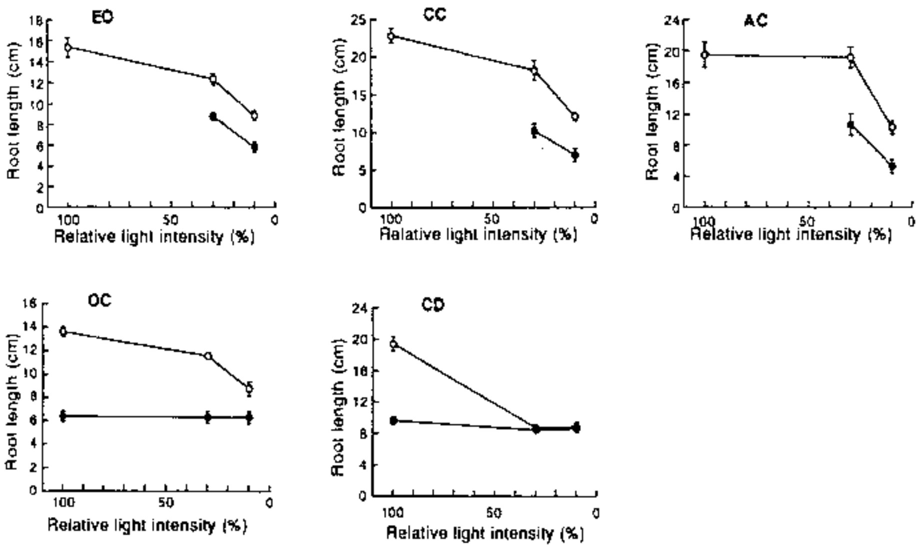

Figure 3. Combining effects of powdered fresh leaf and shading on the receptor plants of the root length. EO: *E. odoratum* , CC: *C. crepidioides* , AC: *A. conyzoides*, OC: *O. corniculata* and CD: *C. dactylon* . ○ : control (humus powder), ●: fresh leaf powder. Bar indicates s.e. of the mean.

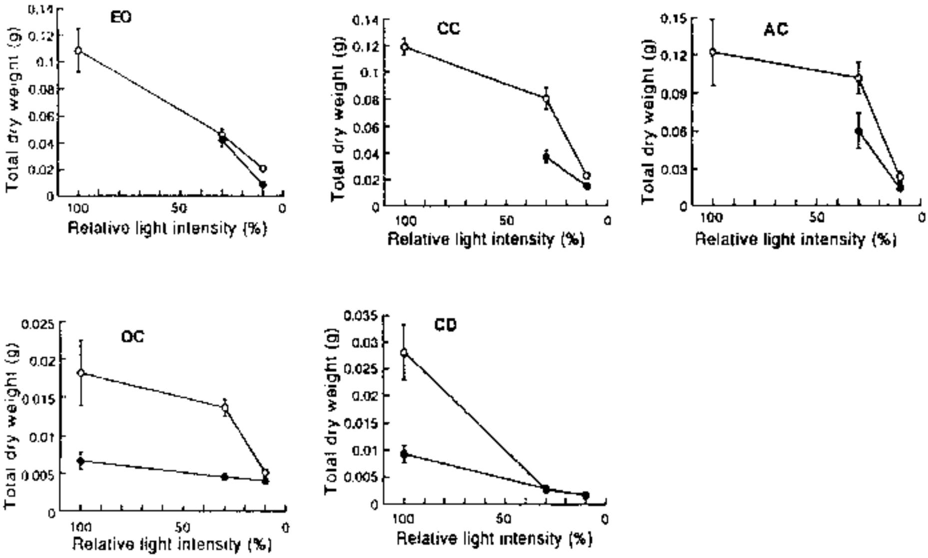

Figure 4. Combining effects of powdered fresh leaf and shading on the receptor plants of the dry wight. See Fig. 3 for symbols.

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COLONIZATION BY THE ANNUAL WEED, *EMEX AUSTRALIS*

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Summary. Experimental introductions of the annual weed *Emex australis* were made in 2 consecutive years at a site in the Western Australian wheatbelt. Introductions differed in relation to the number of seeds involved and whether these were buried or surface-sown. Fates of the introductions were monitored for 30 months. The outcome of the introductions varied markedly according to the year of introduction. Successful colonizations (introductions producing at least one viable seed) were more frequent in the first set of introductions. Relationships between introduction size, seed burial status and colonization success were also different between the separate introductions. Since seedling mortality was low throughout the study, processes affecting seed burial and seed mortality are considered to be the major stochastic factors which influence the colonizing success of *Emex*.

INTRODUCTION

While some understanding has been gained of the characteristics of successful weed invaders (9), it is not possible to predict the outcome of colonizing episodes (3). The fate of an introduction depends upon the action of two groups of variables. The first includes the biological and ecological characteristics which together constitute the weed's 'preadaptation'. The other group subsumes random variables, *viz.* the environmental and demographic stochasticity which often play decisive roles in individual introductions (3). Given the importance of the latter group, it is surprising that so little attention has been paid to the role of chance in the invasion process. Weed invaders are particularly suitable subjects for this type of investigation since they are less mobile than other pests.

The object of this study was to investigate the influence of stochastic factors upon the colonization success of the annual weed *Emex australis* Steinh. (henceforth *Emex*). *Emex* is a self-compatible annual which is native to South Africa. It is an important weed throughout the wheatbelt of southern Australia, but has had the greatest economic impact in Western Australia. Undesirable effects of *Emex* include yield reduction in cereals (6,13), contamination of dried fruit (2), and lameness in sheep (4).

METHODS

Seeds of *Emex* were introduced to an annual pasture on a sandy loam at Wongan Hills Research Station (approximately 200 km north-east of Perth). Introductions varied according to the numbers of seeds (=achenes) involved (n = 1, 2, 4, 8 or 16) and whether seeds were surface-sown or buried at 2 cm. After the soil had been sieved to remove any resident *Emex* seeds, fresh seeds (>90% viability, obtained from seed cleaners in Geraldton) were sown inside 15 cm diameter PVC rings. Because a higher frequency of colonization failure in the smaller introductions was anticipated, the degree of replication decreased with increasing seed number, i.e. there were 20, 10, 5, 4, and 3 replicates, respectively, for the seed numbers given above. Treatments were distributed in a completely randomized design, comprising a block of 12 rows of seven rings with intra- and inter-row spacings of 50 and 100 cm, respectively. Introductions were made at each site during April in 1989 and 1990. The latter set of introductions was made in a separate block with twice the level of replication.

During each growing season, monthly records were obtained of newly emerged seedlings. Since the experiment was fenced in order to prevent disturbance by grazing stock, it was necessary to reduce the biomass of other species by artificial means. The area immediately adjacent to each ring was sprayed with glyphosate in early winter. Within the rings, other species were clipped periodically, but biomass reduction became more difficult to achieve as the season progressed. At the end of each growing season, *Emex* plants were harvested and the number of seeds produced by each plant was recorded.

Introductions were monitored for 30 months, at which point all remaining seeds were retrieved and tested for viability with tetrazolium chloride. Introductions were then classified as 'successful' (seedling establishment within a ring followed by the production of at least one viable seed), 'failed' (neither seeds produced nor viable seeds remaining) or 'indeterminate' (no seeds produced but at least one viable seed remaining). The effects of seed number and seed burial upon colonization at individual sites were analyzed by fitting a log-linear model (7) to the number of introductions falling within each outcome category (successful, failed or indeterminate).

RESULTS

The distribution of the fates of introductions (i.e. the proportions of outcomes in successful, failed or indeterminate categories) differed markedly between the two separate introductions (Tables 1, 2). While the effect of seed number upon introduction fate was highly significant ($P<0.001$) in the first (1989) introduction (Table 1), it was insignificant in the second. Similarly, there was a highly significant ($P<0.001$) effect of seed burial for the first introduction only (Table 2).

Table 1. Fates of buried *Emex* introductions at Wongan Hills, determined over a 3 year period

Year of introduction	Number of seeds introduced				
	1	2	4	8	16
1989	85 (10)[a]	100 (0)	100 (0)	100 (0)	100 (0)
1990	30 (62)	15 (50)	40 (40)	50 (25)	100 (0)

[a] Figures represent the percentages of successful and (failed) introduction, respectively. Indeterminate introductions can be derived by subtracting the sum of the figures from 100.

Viable seeds were detected in a substantial number of introductions which had failed to yield reproductive plants (Tables 1,2). These seeds had remained dormant for the duration of the 30 month experimental period and presumably could had germinated had the experiment not been terminated. However, most emergence occurred during the first growing season following introduction (results not presented).

Table 2. Fates of surface-sown *Emex* introductions at Wongan Hills, determined over a 3 year period

Year of introduction	Number of seeds introduced									
	1		2		4		8		16	
1989	15	(50)[a]	10	(40)	40	(40)	75	(0)	100	(0)
1990	5	(88)	5	(90)	10	(30)	12	(75)	17	(67)

[a] Figures represent the percentages of successful and (failed) introduction, respectively. Indeterminate introductions can be derived by subtracting the sum of the figures from 100.

The mean reproductive output of introductions was generally low (Table 3). While the numbers of seed produced increased with introduction size in the first set of introductions, no such trend was evident for the second set.

Table 3. Cumulative number of seeds produced per introduction by burial at Wongan Hills

Year of introduction	Number of seeds introduced									
	1		2		4		8		16	
1989	14	(4)[a]	13	(3)	25	(9)	39	(16)	123	(40)
1990	24	(9)	15	(8)	39	(19)	41	(17)	21	(13)

[a] Values in parenthesis are standard errors.

DISCUSSION

Results from this study show the importance of timing to the outcome of weed introductions. Since each introduction had a quantitatively different outcome, misleading conclusions could have been drawn about the colonization process if only a single introduction had been made. This work was part of a larger study involving two other sites (East Chapman and Manjimup). In an attempt to arrive at general conclusions, we will emphasize results from the 1989 introduction, since these were consistent with results from parallel introductions made elsewhere (F.D. Panetta, unpublished data).

Provided *Emex* seeds are buried, a high proportion of introductions are successful, even when few seeds are involved. While levels of seedling mortality were low (<10%), seed mortality was sometimes high (Tables 1, 2). It is clear, therefore, that the major stochastic phenomena controlling the fate of *Emex* introductions are processes which influence either seed mortality or seed burial. A degree of seed burial is required for germination (F.D. Panetta, unpublished data), but *Emex* seeds are sufficiently long-lived to take advantage of natural burial processes, e.g. the soil movement which accompanies rainsplash, erosion, grazing or trampling. Cropping activity buries many seeds, partially explaining the prominence of *Emex* in crop/pasture rotations (5).

For both buried and surface-sown seeds in 1989 introduction, the probability of colonization success increased with introduction size (Tables 1, 2). Most colonization failures occurred in the single-seeded introductions, but in natural situations, prominent dispersal vectors (r.g. contaminated agricultural products or tyre treads) could be expected to deposit seeds in small groups.

Emex is able to spread its colonizing effort over a number of seasons through seed dormancy, thus capitalizing on any interyear variations in growing conditions. Martins and Jain (8) found a similar spread of colonizing effort in their experimental introductions of *Trifolium hirtum*. There was evidence that late-emerging *T. hirtum* plants were genetically distinct (8), but such is not likely to be the case for Australian *Emex* populations (10). The presence of seed dormancy may incur costs during colonizing episodes (12). However, such costs are reduced when the probability of seed survival its high (1).

As long as the number of individuals remains small, a colony will be prone to extinction arising from either environmental or demographic stochasticity (3). A fundamental problem in the study of colonization is that some failures are easily demonstratable, but a successful outcome is considerably less so. We have defined a successful introduction as one where at least one viable seed is produced. However, colonization success for an annual species must be some positive function of its reproductive output early during a colonizing episode. Seed production by an *Emex* plant is a negative function of the biomass of its neighbours; *Emex* has been shown to be a poor competitor against such pasture associates as *Trifolium subterraneum* and *Hordeum glaucum* (11). In the present study, *Emex* survivorship and reproduction were probably enhanced, since interspecific competition was reduced through clipping and treatment with herbicides. To this extent, our estimates of its colonization success may be inflated.

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CHANGES OF WEED COMMUNITIES IN LOWLAND RICE FIELDS IN KOREA

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Summary. Changes of the weed communities in lowland rice fields throughout Korea were determined by sampling 2,459 sites in 1992. In 1971 the dominant weeds were all annuals except for *Eleocharis acicularis*. By 1981 the dominant weeds were *Monochoria vaginalis* > *Sagittaria pygmaea* > *Potamogeton distinctus* > *Sagittaria trifolia* > *Cyperus serotinus* > *Rotala indica*. The dominant weed in 1992 was *Eleocharis kuroguwai*, followed by *S. trifolia* > *Echinochloa crusgalli* > *M. vaginalis* > *S. pygmaea* > *C. serotinus*, of which only *E. crusgalli* and *M. vaginalis* were annuals. Perennial weeds such as *E. kuroguwai* and *S. trifolia* have increasingly become the most predominant weed species in 1992. Unlike 1981, *E. crusgalli* was a particular dominant weed species in lowland rice field.

INTRODUCTION

A recent change of cultural practices in lowland rice field of Korea from machine transplanting of aged seedling (35 days) to that of infant seedling (8-10 days) or direct seeding would evoke different responses from different weed species. Similarly, a change from lowland to upland condition introducing of direct seeding would prevent the emergence of semi-aquatic and aquatic weeds but allow upland weeds to take over. A machine transplanted rice cultivation presently constitutes over 95% of the total rice area in this country, while direct seeded rice has become popular since 1988. Weeds in rice field are mostly controlled by chemicals in Korea. Since 1961, repeated application of butachlor, benthiocarb, nitrofen, and 2,4-D in lowland rice fields resulted in the predominance of *C. serotinus* and *E. kuroguwai* (1). Furthermore, a marked build-up of perennial weeds is observed in lowland rice fields of Korea due to chemical management schemes applied continuously since 1975 (2).

The main objective of this nationwide weed survey conducted in cooperation with the Provincial Rural Development Administrations was to determine recent major weeds in lowland rice field, their distribution and importance as affected by cultural practices.

METHODS

The sampling of weeds (total sampling sites: 2,459) was done at two rice fields within each town in 1992. The weeds were counted at 40-50 days after transplanting in the transplanted rice field and at 60 days after seeding in the direct seeded rice cultivation, respectively. The size of quadrat used was 50x50 cm, sampled randomly over the area. The density, biomass, and frequency of individual weed species in each quadrat were determined. The summed dominance ratio was calculated for each weed based on its absolute and relative density, absolute and relative frequency, and importance value.

RESULTS AND DISCUSSIONS

A nationwide weed survey in 1992 was conducted by the Rural Development Administration in lowland rice field of Korea, following surveys in 1971 and 1981. As shown in Fig. 1, the dominant weed species were *E. kuroguwai* (17.5%), *S. trifolia* (15.2%), *E. crusgalli* (8.6%), *M. vaginalis* (8.5%), *Ludwigia prostrata* (4.3%), *P. distinctus* (3.7%), *Aneilema japonica* (3.5%), and *Scirpus juncoides* (2.8%). Those weeds were constituted with 76% determined by the summed dominance ratio in lowland rice fields of Korea. There was a marked build-up of perennial weed, in particular *E. kuroguwai* and *S. trifolia*. In addition, the annual weeds *E. crusgalli*, which was not among the 10 major dominant weed species in 1981, had become a major weed species in 1992. This may have been due to changes in cultural practices and herbicides used in lowland rice fields during this period (Tables 1 and 2). Meanwhile, direct seeded rice and infant rice seedling transplanting technology have gradually increased, as labor saving and cost reducing strategies for rice production in Korea. These cultural practices have also changed the weed community. In direct seeded rice cultivation, annual weed species such as *E. crusgalli* and *M. vaginalis* were prominant (Table 1). In the early stages of direct seeded rice culture under dry paddy condition, the paddy field was under upland condition. Annual weeds may take over, while the emergence of semi-aquatic and aquatic weeds is prevented. Flooding is employed to control weed species that cannot germinate under such a condition. As shown in Table 2, in lowland rice field where 2,4-D, nitrofen, propanil and butachlor have been continuously used, perennial weeds such as *E. kuroguwai* and *S. trifolia* had become the most predominant weed species in 1992. Unlike 1981, *E. crusgalli* was a dominant weed species in lowland rice field. This might be due to increased use of herbicide mixtures for controlling annual and perennial weeds at the same time. This may lower the rate of active ingredient in the herbicide mixture for the control of annual weeds.

Table 1. The dominant weed species as affected by cultural practices in lowland rice field in Korea

Cultural practices	1st	2nd	3rd	4th	5th
Direct seeding					
- Dried	E.c.	C.s.	E.k.	S.t.	L.p.
- Flooded	M.v.	E.c.	L.j.	E.k.	A.j.
Machine transplanting					
- Infant seedling (8-10 days)	E.k.	S.t.	M.v.	S.p.	E.c.
- Aged seedling (35 days)	E.k.	S.t.	E.c.	S.p.	M.v.
Hand transplanting	S.t.	M.v.	A.j.	E.k.	S.p.

E.c.: *Echinochloa crusgalli*
M.v.: *Monochoria vaginalis*
E.k.: *Eleocharis kuroguwai*
S.t.: *Sagittaria trifolia*
C.s.: *Cyperus serotinus*
L.j.: *Leersia japonica*
A.j.: *Aneilema japonica*
S.p.: *Sagittaria pygmaea*

Table 2. Major herbicides used in lowland rice fields in Korea

Year	Total consumption of herbicides (Prod., kg)	Portion of herbicide for lowland rice field (%)	Major herbicides		
			1st	2nd	3rd
1961	9,610	-	2,4-D (100)		
1965	25,323	-	PCP (49.1)	2,4-D (31.4)	Propanil (14.3)
1970	4,957,585	97.7	Nitrofen (44.5)	PCP (21.7)	Chloronitrofen (11.3)
1975	28,398,840	88.1	Butachlor (50.0)	Nitrofen (42.9)	Chloronitrofen (11.3)
1980	47,164,924	79.5	Butachlor (66.5)	Alachlor (9.3)	Thiobencarb (8.8)
1985	49,430,965	74.6	Butachlor (53.1)	Alachlor (13.8)	Thiobencarb (7.7)
1990	70,948,000	68.5	Butachlor (27.9)	Alachlor (14.6)	Butachlor + bensulfuron methyl (12.9)

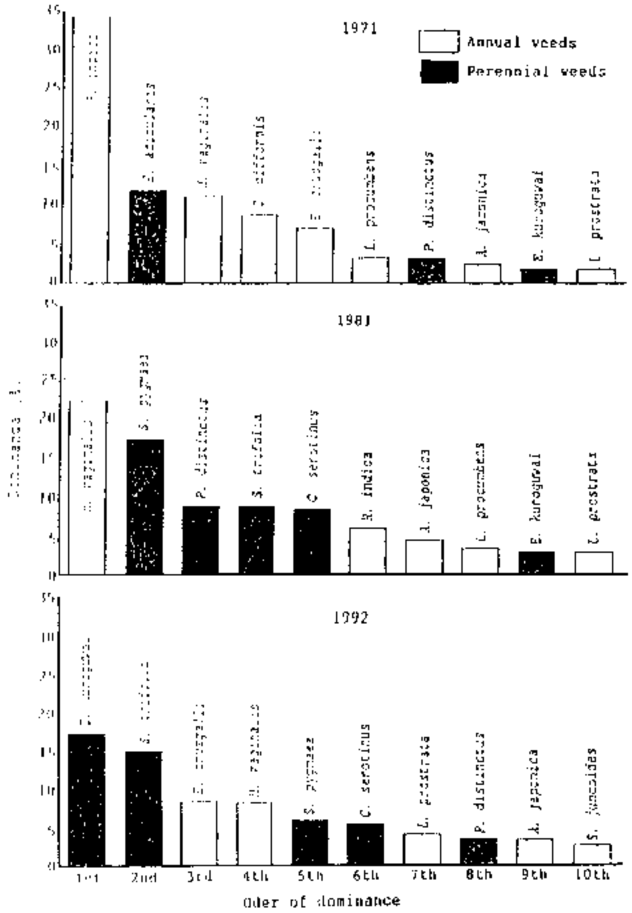

Figure 1. A change of dominant weed species in lowland rice fields of Korea.

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WEED POPULATION SHIFTS IN CROP FIELD IN SHANGHAI APPROPRIATE CONTROL STRATEGIES

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Summary. A survey carried out in 1981 showed that the percentages of weed infestation areas in different crop fields in Shanghai was 68.2%, 75% and 78.8% in wheat, rape and rice field respectively, A similar carried out in 1991/1992 showed that this value was 91.6%, 94% and 84.8% respectively.

The flora also shifted significantly between 1981 and 1991/1992, some major weeds including *Alopecurus aequalis*, *Malachium aquaticaum* and *Cyperus difformis* were successfully controlled, while the more herbicide-tolerant weeds including *Backmannia syzigachne*, *Polypogon fugax*, *Juncellus serotina* and *Sagittaria pygmeae*, increased their infestation rate to 34%, 21%, 19.8% and 30.8% respectively. These changes are due to repeated rice-wheat rotation, reduced tillage and repeated application of single herbicide such as CHLOROTOLURON in wheat fields and NITROFEN in rice fields. They will be well managed by selecting suitable cropping systems, high active or mixed herbicides and effective integrated weed control systems according to the weed flora in fields.

INTRODUCTION

MCP was introduced successfully to control broad-leaf weeds and sedge weeds in rice seed-beds in Shanghai in 1965-1967, 2 years later NITROFEN was tested and extended to control *Echinochloa crus-galli*, *Cyperus difformis* and some annual broad-leaf weeds in rice seed beds and transplanting fields. Controlling weeds in rice fields with these herbicides is more economic and efficacious than hand weeding, and farmers adopted these herbicides rapidly, opening the first page in history of chemical weed control in Shanghai (1). But MCP can not control *Echinochloa crus-galli* and NITROFEN is not efficacious enough for controlling this weed too, so some years *Echinochloa crus-galli* became a more serious problem weed. SATURN and MACHETE were introduced for controlling E*chinochloa crus-galli* in rice fields in 1981-1982, but these two herbicides are not efficacious for controlling perennial weeds in rice fields. CHLOROTOLURON was introduced for controlling *Alopecurus aequalis*, *Malachium aquaticum* in wheat and barley fields in Shanghai, and some years later *Galium aparine*, *Backmannia syzigachne* and *A. japonicum* became problem weeds. The shifts of field weed population became a new problem after ten years. In 70% of fields where herbicides are used to control weeds in Shanghai now, the problem is more and more serious, but little attention is paid to it.

MATERIALS AND METHODS

Investigation with five-scale visualization method was conducted in 5000 field plots in 1981 and the same field plots in Shanghai suburbs in 1991, 50 fields were disposed for one crop in every village (3).

The effects of three cropping systems on field weed population shifts was tested in 1985-1988 in QinDon farm, where every treatment is 0.1 ha. The effects of herbicides on weed population shift in fields were tested with small plots in QinDon farm and 5.4 state farm and experiment farm of Shanghai Academy of Agricultural Science, every small plot 20 meter square, three replication.

RESULTS AND DISCUSSION

According to author's survey with five-scale visualization in 1981-82,the percentages of weed infestation areas in wheat, rape and rice fields in suburbs of Shanghai were 68%, 75% and 78% respectively, the percentages of over-medium infestation areas were 34%, 50% and 42% respectively. However in 1991, the percentages of weed infestation areas reached 91%, 94% and 84.8%, respectively, the percentage of over-medium infestation areas reached 79.6%, 86% and 54% respectively, the percentages of weed infestation areas increased by 19%, 25.6% and 6% respectively, the over-medium infestation areas increased by 45.6%, 36% and 12% respectively from 1981 to 1991 (Tables 1 and 2).

Table 1. Variation of weed population in wheat fields in Shanghai

Weed species	Infestation area (%) May 1981					Infestation area (%) May 1990				
	1	2	3	4	5	1	2	3	4	5
Alopecurus japonica	16.8	4.4	0.3	0	0	20.5	8.5	4.0	9.0	5.0
Backmania syzigachne	45.2	7.6	1.7	0.2	0	27.0	17.0	8.5	4.5	3.5
Sclerochloa kengiana	29.4	12.0	5.9	1.7	0.4	23.2	11.6	9.6	4.8	2.4
Polypogod frugar	36.3	6.9	1.3	0.8	0.2	41.5	12.5	7.5	5.0	4.0
Alopecurus aequalis	35.1	19.7	10.1	4.3	1.4	42.5	7.5	4.5	1.5	0.5
Malachium aquiticum	52.9	28.3	6.3	1.2	0	71.5	7.5	1.5	0	0
Total weed infestation date		68.23		34			91.6		79.6	

Table 2. Weed population shifts in rice fields in Shanghai

Weed species	Infestation area (%) 1981.10					Infestation area (%) 1990.10				
	1	2	3	4	5	1	2	3	4	5
Echinochloa crus-galli	49.2	38.8	10.0	10.0	1.2	57.6	23.2	5.6	2.4	2.8
Cyperus difformis	67.2	10.4	0	0	0	28.8	2.4	0	0	0
Monochoria vagenalis	45.2	2.8	0.8	0.8	0	52.0	7.2	0.4	0	0
Rotala indica	40.0	10.8	1.6	1.6	0	26.0	4.0	0.8	0	0
Ammannia baccifora	52.4	0.8	0	0	0	40.8	2.0	0.4	0	0
Eclipta album	52.4	0.8	0	0	0	45.8	4.0	0	0	0
Sagittaria pygmaea	9.6	3.2	0	0	0	16.8	11.6	4.8	0.8	0
Juncellus serotina	14.4	2.0	0.4	0	0	35.2	20.4	10.0	1.2	1.6

The population composition of weed communities also changed greatly since 1981, all this change was induced by the following factors:

Single type herbicides were used continuously. Some herbicide-sensitive weeds were controlled, for example, the CHLOROTOLURON-sensitive weeds, *Alopecurus equalis*, *Malachium aquaticum*, the NITROFEN and MACHETE-sensitive weeds *Cyperus difformis*, *Echinochloa crus-galli* and *Rotala indica* were controlled successfully (Figs 1 and 2), the percentage of infestation areas of those weeds decreased 21.5%, 26.8% and 8%, 18%, 7.6% respectively, while the infestation areas of the CHLOROTOLURON-tolerant weeds, *A. japonicus*, *Backmannia syzigachne*, *Polypogon fugax* and the NITROFEN and MACHETE-tolerant weeds *Juncellus serotinum*, *Sagittaria pygmaea* increased by 34%, 21.8%, 19.8% and 14%, 30.8% respectively from 1981 to 1991 (Tables 1 and 2).

Continuous rice-wheat rotation cropping system was extended. The crop system of paddy-rice with upland crop (cotton, corn or soybean) as an efficacious, economic and safe method for weed control. For example, the infestation areas of *A. japonicus*, *B. syzigachne* and *Saggitaria pygmaea*, *Echinochloa crus-galli* in paddy rice-wheat with upland crop (cotton, corn or soybean) rotation cropping system are reduced by 50-90% as compared to those in continual rice-wheat rotation cropping system. It was proven that the germination rate of *A. japonicus*, *Backmannia syzigachne*, *Sclechloa Kengiana* was 39.3%, 83% and 62.7% repectively in rice-wheat rotation field after seed buried in soil for 2 years, but the germination rate of these weeds was 0-1.7% only in cotton-wheat rotation fields (Fig. 3).

Wheat-wheat continuous cropping system was practiced year by year. According to the test data the blossom and seed ripening of weeds in wheat fields almost coincide with those of wheat, so all of the weed seeds are falling into soil while we harvest wheat. The weed infestation will get serious in wheat-wheat continuous cropping field year by year, but if we plant green manure, all weeds will be killed while we harvest crop and at the same time, the weed seeds are not ripe yet. Almost no ripe weed seeds are left in soil, so the weed infestation in most years will be reduced compared with wheat-wheat continuous cropping fields (Fig. 4).

No-tillage system was developed and introduced. Weed plants can be killed by cultivation. The tubers and rhizomes of perennial weeds will be turned up to soil surface by a plow and cultivations in autumn, the tubers will be killed by minus zero temperature in winter. According to the author's test, the tuber of juncellus serotina will be killed by low temperature at -3 to -5°C in 2-3 days. The plow and cultivation are the traditional and efficacious way for weed control in fields for long period, but in recent years the development of rural enterprises gave rise to a large-scale transferring of labor power from crop production to industry and side-line occupation, the no-tillage system was rapidly adopted by farmers, this is one of the causes of more and more serious weed infestation, especially in the case of perennial weeds.

A safe effective and economical weed control could only be achieved by integrated weed management. The following suggestion may be preferable in this regard:

The planting areas of upland crops like cotton, corn and soybean, green manure crops should be enlarged and a scientific cropping system, including the rotation of upland crop (cotton, corn, soybean), with paddy crop (rice) or wheat-green manure-rape be established.

The use of mixed herbicides is helpful to control a broad spectrum of weed species according to different population composition of field weed communities, but the antagonism between different herbicides should be noticed. The mixture of CHLORSULFURON + CHLOROTOLURON can be used in grass weeds dominating fields such as *Alopecurus aequalis*, *A. japonicus*, *Bacmannia syzigachne* and broad leaf weed *Galium aparine* dominating field. Otherwise, PUMA can be applied at first and BENTAZON later. MACHETE + LONDAX mixture can be used for the control of annual weeds, such as: *Echinochloa crus-galli*, *Monochoria vaginalis* and perennial weeds, such as: *Juncellus serotina* and *Sagittria pygmaea*, otherwise, MACHETE can be applied at first and BENTAZON, MCP later.

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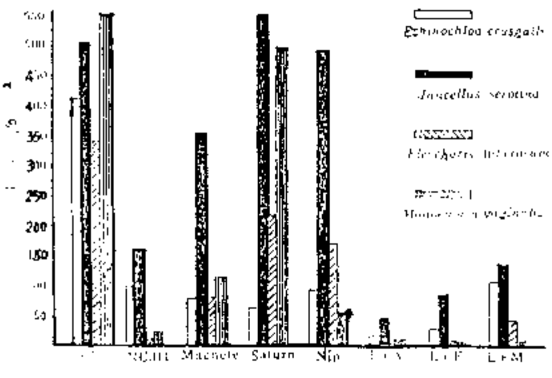

Figure 1. Effects of herbicides on weed populations shifts in rice fields

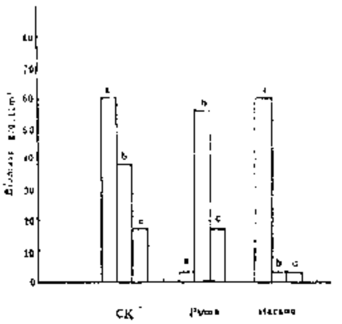

Figure 2. Effects of herbicide treatment on weed populations
a. *Alopecurus aequalis*;
b. *Malachium aquaticum*;
c. *Galium aparine*.

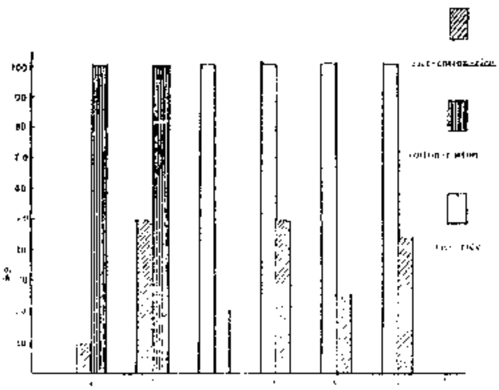

Figure 3. Effects of crop rotation on weed populations
a. *G. aparine*; b. ?. *sanguinalis*;
c. *A. acqualis*; d. *M. aquaticum*;
e. *C. difformis*; f. *E. crus-galli*.

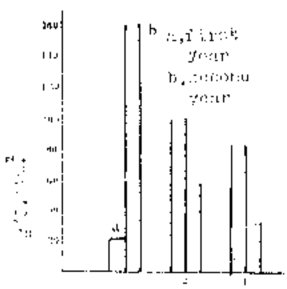

Figure 4. Effects of crop rotation on *Alopecurus aequalis* infestation
1. wheat-rice-wheat;
2. wheat-rice-rape;
3. wheat-rice-green manure.

THE BIOLOGY OF *LOLIUM*: WILL *L. TEMULENTUM* BE SIMILAR TO *L. RIGIDUM* AND THREATEN CROP ROTATIONS IN WESTERN AUSTRALIA?

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Summary. Each year in Western Australia more than 20 farms deliver wheat and barley infested with drake (*L. temulentum* L.). The seeds can be poisonous and contaminated grain is unacceptable for overseas markets. Drake may be more widespread than realised presently because it can be misidentified as a variant within the annual ryegrass complex (*L. rigidum* and its hybrids). Biotypes of *L. temulentum* from Western Australia have innate and enforced seed dormancy; vigorous seedling growth; high seed production. Unless special cleaning measures are used the weed is sown with crops established from seed saved on the farm. *L. temulentum* produced less regrowth after defoliation than *L. rigidum* and may be sensitive to grazing. *L. temulentum* is unlikely to become more widespread in Western Australia if clean seed is sown and an integration of methods is used for its management, including a phase of grazed pasture. However, the awned biotype of drake (*L. temulentum* var. *temulentum*) which is prevalent in Western Australia may be more able to survive the current farming systems than the biotypes introduced into other parts of Australia and which have not flourished.

INTRODUCTION

Each year in Western Australia more than twenty farms produce barley and wheat which is infested with drake (*Lolium temulentum* L.). The seeds of drake can be poisonous (4) and contaminated grain needs expensive recleaning to meet the low, or zero, tolerances of markets. Drake grows throughout the wheatbelt of Western Australia but it seldom reaches densities that cause concern to many farmers. However, the incidence of the weed is unpredictable and those that receive grain for export markets do not want the weed to increase. Elsewhere in Australia drake is rare or extinct (10) and in other countries it is an endangered species (7) or a weed that needs to be controlled (12).

The variable incidence and status of drake is intriguing, particularly when compared with the widespread and troublesome annual ryegrass (*Lolium rigidum* L. and its hybrids). In part, the problem is due to difficulties with identification of species and hybrids within the *Lolium* genus. However, regional differences will be due to variations within, and between, the *Lolium* species and their interactions with climates, soils and farming systems. This paper develops several hypotheses to explain the current distributions of drake, and to predict the factors which could cause it to increase in Western Australia. Comparisons with *Lolium rigidum* may strengthen the outcomes of the investigation of drake and also provide further insights into the nature and distribution of weeds.

MORE WIDESPREAD THAN CURRENTLY RECOGNISED?

Drake may be more widespread than currently recorded but identified incorrectly as *Lolium rigidum*. Kloot (10) concluded that there were four *Lolium* species that could be weeds of Australian agriculture. Three of the species outcross (*L. perenne*, a perennial; *L. multiflorum*, a short-lived perennial; *L. rigidum*, an annual) and produce interbreeding hybrids which form populations with individuals that have all possible characteristics of the parent species. These crosses with *Lolium rigidum* retain the annual habit and could, therefore, cohabit sympatrically with the annual, self-pollinating *Lolium temulentum*. Consequently, *Lolium temulentum* could be in the same fields as *Lolium rigidum* and its hybrids and, if unrecognised, identified incorrectly as "annual ryegrass" (*L. rigidum*).

All annual *Lolium* species are characterised by glabrous, shiny leaves. Compared with *Lolium rigidum*, our Western Australian collections of *Lolium temulentum* have seedlings with larger more erect leaves and only a few tillers. However, individuals within *Lolium rigidum* populations were as large and erect as *Lolium temulentum*. Differences in the morphology of the inflorescence and seed (caryopsis plus adhering glumes) make it possible to distinguish between *Lolium rigidum*, and its hybrids, and *Lolium temulentum* (10). The spikelets are more widely spaced on the spike, particularly at its base, and the seeds are larger and ovoid (Fig. 1). The long awns of drake (*L. temulentum* var. *temulentum*) differ from its awnless biotype (*L. temulentum* var. *arvense* [With.] Liljebl) and the awnless *L. rigidum* and its hybrids.

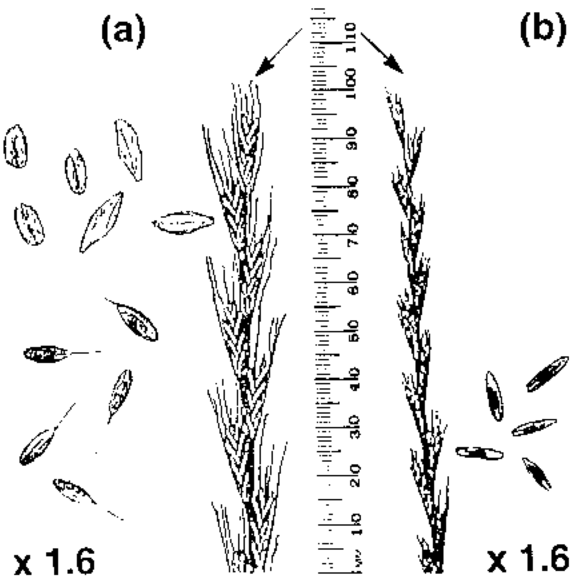

Figure 1. The terminal spikelets and seeds (caryopsis plus adhering glumes) of the awned biotype of drake (a) and of annual ryegrass (b).

BIOTYPE INTRODUCTIONS OF DIFFERENT ADAPTABILITIES?

Drake may have adapted successfully to Western Australia because the introductions came from the Mediterranean regions of Europe. It is known that drake is adapted to regions from northern Europe, with summer growth and freezing winters, to Mediterranean regions, with winter growth and long dry summers (9). Perhaps the lack of persistence of drake in other parts of Australia is because the introductions to those parts were from the more northern regions of Europe and less adaptable to the long, dry summers of southern Australia.

It would be expected that seed dormancy for summer survival would be an important attribute for success in Mediterranean climates. It was suggested that drake has no dormancy (5; 8) but drake from Western Australia has both innate and enforced dormancy (2). These differences in dormancy may be due to sources of seed with that from Western Australian produced by biotypes better adapted to Mediterranean climates. Annual ryegrass is well adapted to the Mediterranean climates of southern Australia and it has innate and enforced dormancy also (6).

The responsiveness of flower initiation by drake to photoperiod and vernalisation differs among biotypes (5). A summer annual biotype (Ceres) requires an exposure of only one day with a photoperiod greater than nine hours to switch plants from vegetative to reproductive growth. A winter biotype from Turkey, however, had a critical photoperiod of more than 14 hours (5). The photoperiod requirements of the Western Australian biotypes for flower initiation are not known but plants grown in late summer initiated reproductive growth whereas *Lolium rigidum* continued to make vegetative growth (Fig. 2). The winter biotypes of drake respond to vernalisation whereas the summer types are unresponsive (1; 5). *Lolium rigidum* responds also to photoperiod and vernalisation but Mediterranean types had a low vernalisation response (3).

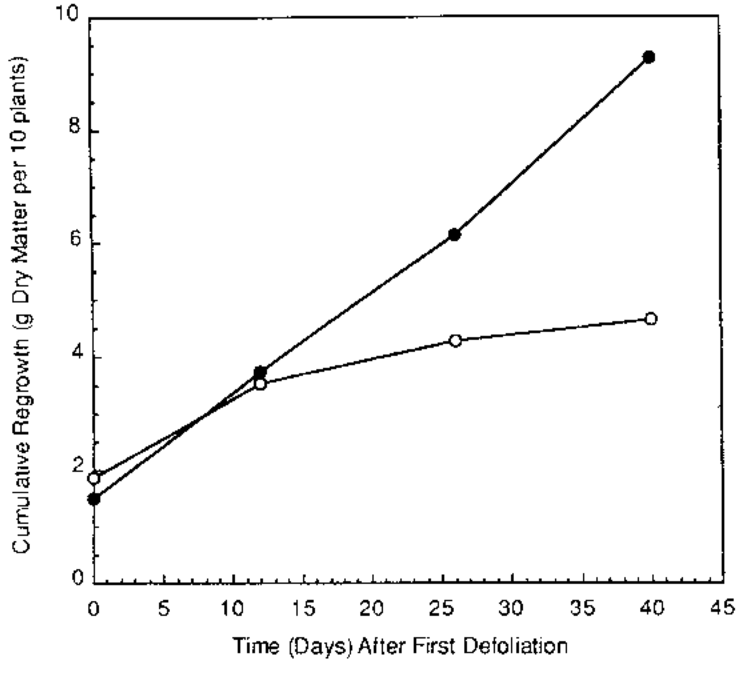

Figure 2. The response of *Lolium* species to frequent defoliation during February-March 1993 in a daylight phytotron, Perth, Western Australia (32° South Latitude; 13-14 hours daylength; 25°C/15°C day/night temperatures) of the awned biotype of drake (o) and of annual ryegrass (•). The mean coefficient of variation for a datum point (n=4) was 10%.

ENCOURAGED BY FARMING SYSTEMS?

Drake may have adapted more successfully to regions of Western Australia because of the types of farming systems practiced there. Discussions with farmers who have infested grain suggests that drake is more of a problem on light textured soils that are cropped frequently without the use of herbicides for grass control, and without a grazed pasture in rotation with the cereal crops. Additionally, farmers in these regions routinely save a portion of their crop as seed for subsequent crops and if infested with drake then the weed is sown with the crop. The awned biotype of drake seems more persistent than the awnless type which supports the proposition that drake is an obligate weed of cereals, since it would be more difficult to separate from cereal grains by seed-harvesting machinery. For example, accessions in the Herbarium of Tasmania are only the awnless biotype and the species may be extinct in that State. In Western Australia, however, cereal seed is contaminated by the awned biotype of drake and the awnless biotype has not been seen recently.

Herbicides, and their rotations, are used widely in crop rotations across southern Australia for weed control. The expectations would be that current methods of cultural and chemical control of grass weeds would control drake also. However, it was suggested (2) that delayed germination of drake by warm temperatures may enable it to escape early cultural and chemical treatments. Resistance of annual ryegrass to herbicides is of major concern across southern Australia (11) but we have very little information on the response of drake to herbicides.

CONCLUSIONS

The persistence of drake in Western Australia may be due to the introduction of adaptable biotypes from Mediterranean regions of Europe. These adaptable types may have been encouraged by the farming systems of low inputs of herbicides, minimum tillage, rotations that have low grazing pressures and infrequent use of crops other than cereals, and the use of seed from crops infested with drake. The required elimination of potentially poisonous contaminations of drake will require its recognition as a different species from annual ryegrass, a greater intolerance of its presence in crops, and a reversal of those factors that encourage it. The hypotheses proposed in this paper require validation if management programs are to be based on sound knowledge of the biology of the weed.

ACKNOWLEDGEMENTS

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COMPARISON OF THE ECOLOGY OF BITOU BUSH AND BONESEED (*CHRYSANTHEMOIDES MONILIFERA*) IN SOUTH AFRICA AND AUSTRALIA

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Summary. The ecology of the biological control targets, bitou bush, *Chrysanthemoides monilifera rotundata*, and boneseed, *C. monilifera monilifera* in their native habitat, South Africa, are compared with weed infestations in their country of introduction, Australia. Taxonomic and distribution differences between bitou bush and boneseed implies that two sets of agents will be required. Boneseed and bitou bush plants in South Africa produced significantly less seed than in Australia. For bitou bush this was largely due to fewer flowers. Mature plant densities can however be similar in the two countries. Biological control aimed at reducing flower numbers through herbivory, would reduce seed set and also reduce competition with native flora in Australia. Control of infestations in Australia will require combining biological control with management, probably by fire.

INTRODUCTION

The southern African shrubs, bitou bush, *Chrysanthemoides monilifera rotundata* and boneseed, *C. monilifera monilifera*, are weeds in Australia and are the targets of a biological control program. Their importance and ecology in Australia was established in a number of studies (17, 18, 20, 21). Comparisons of plant abundance have been made between *C. monilifera* in South Africa and Australia (16, 19), although the South African plants used in the comparison, from Knysna on the south coast of Cape Province, were probably *C. monilifera pisifera*, a subspecies not found in Australia (4, Scott, unpublished observations). Reports that *C. monilifera* was much less abundant in its native region of southern Africa (16, 19) and that the plant is attacked by insects likely to be host specific (10) has lead to a search for biological control agents. The ecology of bitou bush and boneseed was studied during the search for biological control agents in South Africa. In this paper I make a comparison, in the context of biological control, of the distribution and abundance of these weeds in their native habitat, South Africa, with that of the weeds in their country of introduction, Australia.

METHODS

Information of the ecology of bitou bush and boneseed in Australia was obtained from published sources. The ecology of bitou bush and boneseed in South Africa is based on study sites monitored from 1987 to 1989 (1, Scott unpublished). Boneseed was studied at two sites: Devil's Peak and St James in Cape Province. Bitou bush was studied at five sites in Natal: The Bluff, Palmiet, Mtunzini, Nseleni and St Lucia. Flowers and seeds were counted on 20 randomly chosen plants at three month intervals at each site. Seedlings and mature plant were counted during the study and seed bank densities were measured at the end of the sampling period. Full details of this study will be reported elsewhere (Scott unpublished).

RESULTS AND DISCUSSION

Taxonomy. Identification of *Chrysanthemoides* subspecies is simpler in Australia than in South Africa where there are at least 7 taxa and different forms and intergrades between forms (4, 12). Bitou bush and boneseed only overlap in the Ulladulla - Sydney region in Australia, but hybridization appears rare (15). Hybrids are not known from South Africa where bitou bush and boneseed are geographically widely separated (12). There are considerable morphological differences between the two subspecies as illustrated by Norlindh (12). Thus it is likely that studies of the genetic variability of bitou bush and boneseed will show that they are separate species. The difference between bitou bush and boneseed also implies that two sets of biological control agents will be required.

Distribution. Bitou bush in Australia is considered to have only occupied part of its potential range (5) when compared to the distribution in South Africa (12). In contrast, boneseed appears to occupy a wider range of climates and habitats in Australia than in South Africa. In Australia boneseed is found in Mediterranean type and temperate climates in South Australia, Victoria and NSW. In South Africa the plant is restricted to the south west Cape Province that has a Mediterranean type climate (12, Scott unpublished). The wide range of climates in which bitou bush and boneseed are found also implies that it is unlikely that a single biological control agent will be effective across the entire range. For this reason several agents are being selected from a wide range of climates, including climates where boneseed is not present in South Africa, but matched to Australian conditions (2).

There is no obvious difference between the soil type preference of bitou bush in Australia and South Africa. Plants in both regions are found on sandy or low fertility soils of granitic or sedimentary origin and on coastal soils (8, 18). Boneseed is found on sandy or low fertility soils of granitic or sedimentary origin and on coastal soils in Australia (18). In contrast, boneseed in South Africa is largely restricted to mid slopes of mountains and lithosols on sandstone, whereas other *Chrysanthemoides* species such as *C. incana* and *C. m. pisifera* are found on the coastal plain (Scott unpublished). The extent to which the distribution is determined by biotic factors such as pathogens or insects or intra-specific competition has not been investigated. Given the wider distribution in Australia, biological control agents found in both coastal and mountain habitats (eg *Comostolopsis germana* and *"Tortrix"* sp.) (1, 14) could be more effective than agents with more restricted distributions (eg some of the chrysomelids).

Phenology. Boneseed has a similar flowering phenology in Australia and South Africa (Table 1). However, because of its relatively short flowering period, alternative hosts may be important to enable a build-up of populations of seed predators such as *Mesoclanis* spp. (9) and for their survival during the non flowering period. *C. incana* and *C. m. pisifera* found near boneseed in South Africa extend the availability of flowers and seed by three months. These plants are absent from Australia. Noble and Weiss (11) point out that to be successful biological control agent, a seed predator would need to cause greater than 95% seed reduction over the entire year and that control would be unsatisfactory if it dropped to less than 90% during part of the year (especially during abundant seed production). Build-up of flower destroying insects and seed predators is more likely to occur on bitou bush because the plant flowers for more of the year than boneseed (Table 1).

Seed production. Although boneseed plants in South Africa and Australia produce similar numbers of ovules per capitula, an order of magnitude less seed is produced in South Africa (Table 1). This order of difference continues into the seed bank. Unfortunately there are no published data available from Australia to extend the comparison as far as mature plants.

More of a comparison is possible for bitou bush. Similar numbers of ovules are formed on the capitula in both countries (Table 1). However in South Africa, the canopy produces a fifth of the capitula and these in turn have a third less seed maturing in comparison with Australia. These differences are carried through into the seed bank and seedlings numbers. There are more plants in South Africa than would be expected given the differences in seed production. This may be due to self thinning of seedlings to the same mature plant density. Plants in South Africa covered less surface area than in Australia. This is likely to be due to the greater range of herbivores present, some of which are being used as biological control agents (eg *Comostolopsis germana*).

Table 1. Comparison of bitou bush and boneseed ecology in southern Africa and Australia. Unsourced data from South Africa come from Scott (unpublished). South African data shows means ± S.E. for the Devil's Peak population of boneseed (N = 20) and means ± S.E. of five populations of bitou bush. Australian data are ranges or means ± S.E. from published sources.

Plant characteristic	South Africa	Australia (Source)
Boneseed		
Flowers	July - Oct.	Aug. - Oct. (18, 17)
Ovules/capitulum	6.5 ± 0.14	5 - 6 (15)
Ripe fruit	Nov. - Feb.	Nov. - Feb. (18)
Seed/m^2 canopy	127 ± 32	3025 ± 450 (17)
Seed bank under plants, seeds/m^2	70 ± 22	800 - 2500 (6)
Seedlings/m^2	0 (unburnt) 1.4 ± 0.2 (burnt)	47 ± 18 (unburnt) 826 ± 255 (burnt) (6)
Bitou bush		
Flowers	Apr. - Nov.	Apr. - Nov. (18)
Ovules/capitulum	11.6 ± 0.2	11 - 13 (15)
Capitulum/m^2 of canopy	164 ± 77	1010 ± 170 (19)
Ripe fruit	Apr. - Jan.	All year (June - Sept.) (17)
Mature seeds/capitulum	2.1 ± 0.35	6.6 ± 0.3 (19)
Seeds/m^2 canopy	924 ± 444	3545 ± 600 (17)
Seed bank under plants, seeds/m^2	37 ± 14	2030 ± 460 (19)
Seedlings/m^2	0.03 ± 0.02 (unburnt)	114 ± 27 (unburnt) (17) 40 ± 16 (burnt)
Plants/m^2	0.2 ± 0.04	0.2 (17), 0.67 (20)
% ground cover	25.6%	37.6% (20)

Biological control. Fire will have a major impact on the biological control program. Boneseed does not resprout after fire in South Africa or Australia (6) and depends on the soil seed bank for regeneration. Lane and Shaw (7) found that boneseed had no seed bank remaining after fire. This also appears to be the case in South Africa. Seedlings appeared following a fire at the Devil's Peak study site, but not in the next year. In contrast to boneseed, 26% of mature bitou bush resprouted in Australia (17) although fire caused loss of seed (17). Fire appeared to have a similar effect on bitou bush in South Africa (Scott unpublished). The seed of bitou bush and boneseed rapidly lose viability in the soil. Weiss (17) reported the percentage viable seed for bitou bush and boneseed after three years to be 2% and 13% respectively. Plants at the South African study sites were mostly of similar age (as estimated from annual growth rings), indicating episodic recruitment, probably following fire (Scott unpublished). Fire combined with seed predation could effectively control populations (11).

The difference in bitou bush seed production between South Africa and Australia results from a lower density of capitula in South Africa (Table 1). A number of biotic factors could be responsible including *C. germana* which has already caused a reduction in flowering in Australia (13). Seed predators such as *Mesoclanis* species were not abundant at the sites and during the sampling period destroyed up to 9% of potential seed. Further studies using insect exclusion experiments (3) could show the role of herbivory in reducing seed production in South Africa. It would be expected that the growth ring increments, which are very evident in *Chrysanthemoides*, would also increase in size once the plant was freed from herbivory in South Africa. Among the first changes to be expected from successful biological control in Australia would be a reduction in capitula number and a reduced growth ring increment. It will still be necessary to manage infestations, probably by fire, to ensure the removal of stands of dense bitou bush and boneseed once there has been a significant depletion of the seed bank.

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ASPECTS OF THE ECOLOGY OF AFRICAN BOXTHORN, *LYCIUM FEROCISSIMUM*

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Summary. Little is known of the ecology and biology of the woody weed African boxthorn. A study of some aspects of the ecology of boxthorn was carried out on a coastal reserve on the west coast of South Australia. No clear evidence was found of boxthorn displacing native vegetation. Fruit production per plant varied but no link between fruit production and plant height was established. A positive, linear relationship exists between boxthorn fruit size and the number of seeds per fruit. Further ecological studies of boxthorn are recommended.

INTRODUCTION

Ecological studies are important for weed control planning. They can assist authorities establish the significance of a weed, its potential to spread (8,12) and provide an objective basis for decisions on quarantine and other legislative responses (1,12,13,16). Such research can also assist the development of control techniques, particularly biological control (3,17), and appropriate control strategies (4). A number of authors have criticised the paucity of ecological studies of weeds and have urged that more work be done in this area (3,6,8,11,16).

African boxthorn, *Lycium ferocissimum* (Miers), is regarded as a serious threat to native plant communities in Australia (10,18) and as a weed of grazing land (7,14,19). It is a declared noxious weed in all Australian states and the Northern Territory (14). Considerable public and private resources are directed to control programs for the plant. Despite this, very little has been published on boxthorn biology and ecology. Clearly ecological research would allow better informed decisions to be made on the status and control of boxthorn.

This paper will describe an initial effort to gather information on the ecology of boxthorn. Results of studies on the impact of boxthorn on coastal vegetation and aspects of its fruit and seed production are presented and discussed.

METHODS

Field measurements for the study were taken on a well established infestation of boxthorn on a coastal reserve at Cape Bauer, 32° 43'S, 134° 03'E, some 20 km northwest of Streaky Bay, South Australia. Two rectangular study sites, each consisting of 52 10x20 m cells, were pegged out. The location of each individual boxthorn was mapped and measurements of height and projected ground cover taken.

Impact studies. To see if there were any differences in vegetation between areas of 'high' and 'low' boxthorn density, a 2x2 m quadrat was sampled in each cell; the quadrats were positioned using the transect/baseline method (2). The number and total % ground cover was recorded for each perennial species. The total % cover of all annual species and % of bare ground was also recorded. The data was then analysed, using a two sample T-test, for differences in mean % cover of perennials, annuals and bare ground and high/low % cover of boxthorn. Differences in the mean number of perennials between high/low numbers of boxthorn were analysed in the same fashion. Significant results were examined further using simple linear regressions.

Fruit production. Two boxthorn plants were randomly selected from five height categories, a total of ten boxthorns. When most fruit were ripe, each plant was progressively felled and its fruit stripped and counted. A one way analysis of variance was used to compare fruit production between the five height categories.

Fruit size/seed number. The relationship between fruit size and the number of seeds per fruit was explored. Eleven boxthorn plants were randomly selected and 20 ripe fruit, representing a range of sizes, were sampled from each. Each fruit was measured for volume and diameter and then dissected and the seeds extracted and counted. Linear regression was then used to examine the relationship between volume and seed number and diameter and seed number.

RESULTS AND DISCUSSION

Impact studies. Results of measurements carried out on vegetation in quadrats classified as high or low for boxthorn are presented in Table 1.

Table 1. Effect of African boxthorn density on other vegetation at Cape Bauer.

Vegetation component	% Cover		Number of individuals (count per 4 m^2)	
	High[a]	Low[a]	High[b]	Low[b]
Atriplex cinerea	6.13	4.21	1.76[f]	1.18[f]
Danthonia spp.	0.26	0.15	1.56	0.60
Lycium australe	0.23	0.32	0.07[g]	0.32[g]
Marieana erioclada	0.13	0.09	0.0	0.0
Marieana oppositifolia	9.06[c]	4.27[c]	0.87	1.20
Nitraria billardierei	6.44	7.95	1.30[h]	0.58[h]
Olearia axillaris	0.21	0.91	0.17	0.32
Sclerolaena parallelicuspis	1.69	1.27	0.82	0.88
Stipa spp.	0.29	0.27	0.87	1.08
Other perennial herbs	0.11	0.43	0.21	0.46
Other perennial shrubs	0.60	4.72	0.56[i]	0.27[i]
Total perennials	26.45	23.92	7.55	7.00
Total annuals-	58.40[d]	37.57[d]	-	-
Bare ground	14.54[e]	36.55[e]	-	-

[a] 'High' boxthorn >2% cover (mean=4.9%), 'low' boxthorn <=2% cover (mean=0.45%)
[b] 'High' boxthorn >2 individuals (mean=5.54), 'low' boxthorn <=2 individuals (mean=0.68)
[c,d,e,f,g,h,i] Means significantly different at P=0.05

Regression analysis was then carried for those vegetation components which showed a significant result (Table 1), to determine if there was any clear relationship between the level of the component and the level of boxthorn. While this produced a number of significant (P=0.05) results, between boxthorn and annuals and boxthorn and bare ground for % cover and boxthorn and coast saltbush, *Atriplex cinerea*, nitre bush, *Nitraria billardierei* and other shrubs for number of individuals, r^2 values indicated a high level of variation in the data. The significant results should therefore be regarded with extreme caution.

As stated earlier, boxthorn is regarded as a serious threat to native plant communities in Australia. It has been suggested that boxthorn is displacing nitre bush on islands off the South and Western Australian coasts (10). However the results presented in table 1 provide no clear evidence of differences in vegetation between areas of high and low boxthorn density. Therefore it would be difficult to reach a conclusion on whether or not boxthorn has displaced native vegetation at this site. A more likely explanation for boxthorn's invasion of this site is that it has taken advantage of a past disturbance (5,9) and is exploiting resources formerly used by other plants that were present prior to the disturbance. Given that the site was grazed by sheep in the past and is currently subject to grazing by rabbits, this is most likely to be the case. Further studies need to be carried out before it can be established what, if any, impact boxthorn is having on native plant communities. Research effort should be directed toward those environments where boxthorn is regarded to pose the most serious threat and where most control resources are currently being directed; for example coastal areas and offshore islands (10,18).

Fruit production. Fruit produced per boxthorn plant ranged from 0 to 535; the mean being 223. This is in contrast to a study in southern Victoria where fruit production ranged from 730 to 4219 over ten plants (Hildebrand, unpublished thesis). The higher figures in the Victorian study are likely to be due to the different environment and the more intensive methodology used.

There was no difference (P=0.05) in the number of fruits produced by plants of different heights. More observations are required before the relationship between plant size and fruit production can be determined.

Fruit size/seed number. Results of boxthorn fruit size and seed number measurements are summarised in Table 2.

Table 2. Size and number of seeds of boxthorn fruit collected at Cape Bauer.

	Volume (cm^3)	Diameter (mm)	Number of seeds
Range	0.1 to 1.0	4 to 12	2 to 67
Median	0.2	7	20
Mean	2.86	7.41	21.40

The range of fruit diameters measured were similar to the 5 to 10 mm reported by Purdie *et al.* (15); however the number of seeds counted per fruit in this study showed wider variation than the 35 to 70 reported by the same authors.

Regression analysis revealed significant (P=0.05) positive linear relationships between fruit volume, diameter and the number of seeds per fruit. However low r^2 values showed some variation in the nature of these relationships between individual boxthorn. Further analysis revealed that these relationships were not significantly different for eight of the eleven plants sampled. Two of the other three plants also showed positive linear relationships but significantly different from the other eight. Thus, further measurements will be required to clearly establish the relationships between volume and seed number and width and seed number. Coupled with a better understanding of fruit production per plant, including the proportion of different sized fruit, knowledge of the nature of the relationship between fruit size and seed number may allow a model to be developed which could estimate the number of propagules produced by an individual or stand of boxthorn.

This study has taken some of the first steps toward a better understanding of boxthorn. It has provided some evidence that boxthorn may not be as clearly detrimental to native vegetation as first thought. Fruit production per plant varies widely and no link between fruit production and plant height has yet been established. There is a positive, linear relationship between boxthorn fruit size and the number of seeds per fruit but further measurements are required to establish the exact nature of these relationships. While the information presented here will not immediately change the way we view boxthorn or its control, it does provide a basis for future ecological studies of this plant. As well as further work on the aspects described above, useful work could be done on dispersal ecology and the germination characteristics of boxthorn seed. Much remains to be discovered about this plant that would be of value to weed control authorities, managers of conservation areas and primary producers.

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SOME ASPECTS OF THE BIOLOGY OF RASPWEED (*HALORAGIS ASPERA*)

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Summary. The objectives, details and results of four germination experiments on the fruit of raspweed are reported. Effects of gibberellic acid, scarification, temperature, light and previous storage regimes on germination and dormancy are highlighted. Results are discussed and field implications are drawn. The importance of raspweed's sexual reproductive strategies as compared to its asexual strategies is noted. A brief indication of raspweed's weediness is also provided.

INTRODUCTION

Raspweed, *Haloragis aspera*, is a member of the Haloragaceae family. It is a native of Australia where it is widely distributed but limited to south of the Tropic of Capricorn. Isolated incidences have been reported in Western Australia and Tasmania. Raspweed is a major perennial weed of cultivation in central Queensland, parts of southern Queensland and north-western New South Wales.

Raspweed it is often referred to as a 'take-all' weed because where it grows nothing else will. Its extensive root system and non-seasonality attribute to its weediness. Little is known about the biology of raspweed and hence management is often difficult. It is a perennial herb up to 30 cm high with annual stems arising from a deep subterranean system. Leaves are up to 4 cm long with hooked hairs giving a raspy texture, hence its common name. The inflorescence is an indeterminate spike of dichasia of 3 to 5 very small flowers. Fruits are small, globular with persistent sepals. The woody exocarp encloses four locules with the potential for all locules to be filled with one pendulous ovule (2). The contribution made by sexual reproduction to the population dynamics of this weed is not fully understood, and while it is not considered the major path of reproduction, the plant devotes much energy toward it (Osten, unpublished data).

Information on the different components of reproductive strategy is necessary for the development of efficient integrated management programs (1). This paper reports on aspects of raspweed's sexual reproduction, emphasising the requirements for germination.

METHODS

During spring 1990 mature fruits were collected from potted raspweed specimens grown in central Queensland. Half of the collection was stored in air tight containers at -5°C for a period of 20 months. The remainder was after-ripened at a constant 25°C for up to 30 months.

Several unsuccessful attempts were made to remove the gel-like seeds from the woody pericarp of the fruit without causing damage to the embryos. Consequently, all germination studies have used the entire fruit capsule.

Four germination experiments were conducted in controlled environment growth cabinets. The first two were undertaken at The University of Queensland in late 1990 and early 1992. The latter two in Emerald in mid 1992 and early 1993. Germination was monitored for six (Experiments 1, 2, 3) or ten (Experiment 4) weeks.

Experiment 1. The objectives were to determine whether freshly collected raspweed fruits have the ability to germinate, the requirements for such and whether the fruits exhibit dormancy. Treatments included a combination of two scarification regimes (scarified and not); four gibberellic acid (GA) concentrations (nil, 0.1, 1.0 and 10.0 mM); three temperature regimes (15, 20 and 25°C) and two light regimes (light and dark). Scarification involved removing the blossom end of the fruits with a sharp scalpel. Darkness was imposed by wrapping dishes with alfoil. The nil GA solution used sterile water.

Experiment 2. The objective was to determine and compare the germination ability of fruits which had been stored at -5°C for 20 months and fruits which have been after-ripened at 25°C for the same period. Treatments were a combination of two light regimes (light and dark); three alternating temperature regimes (18/13, 25/20 and 30/20°C); two GA concentrations (nil and 1.0 mM) and two fruit types (stored -5°C and stored 25°C). All fruits irrespective of fruit type were scarified (as in Experiment 1).

Experiment 3. The objective was to determine the effect of light on the germination of fruit capsules with a longer after-ripening period (24 months at 25°C). Only two treatments were used in this instance (light and dark). All fruit were scarified and every dish had 1.0 mM GA added. All were kept at a constant 14°C.

Experiment 4. The objectives were to determine the germination ability of fruits kept for 30 months at 25°C (compared with previous experiments) and whether dormancy has been reduced such that scarification and GA are no longer necessary to facilitate germination. The treatments were a combination of two scarification types (scarified and not); two GA concentrations (nil and 1.0 mM) and two light regimes (light and dark). Scarification procedures were the same as Experiment 1. All dishes were kept at a constant 14°C.

RESULTS AND DISCUSSION

Experiment 1. Irrespective of treatment, it took at least 21 days for the first fruit to germinate. After six weeks, only 1.7% of the total 1440 fruit germinated. Referring to only that which germinated, and considering each treatment factor on its own, 52% germinated at 15°C, and 28% and 20% at 20 and 25°C respectively. 68% germinated in 1.0 mM GA and 16% in each of the 0.1 and 10.0 mM GA solutions. Of those germinated, 68% were scarified and 64% were in the light. The highest yielding treatments (combined factors) were equal between the 15°C with 1.0 mM GA + scarified + light, and its similar treatment in the dark. Collective data indicate that fresh fruit capsules have a high degree of dormancy. Some degree of dormancy can be broken by scarification and applications of GA. Germination requires cool temperatures and light.

Experiment 2. The first after-ripened fruit germinated only after seven days and the first 'cold' treated fruit after 14 days. Again only 1.5% of the total fruit germinated. Of those germinated, 86% were from the after-ripened batch. Irrespective of fruit type, light regime or GA, 41% germinated at 18/13°C, a further 41% at 25/20°C and 18% at 30/20°C. Considering the other treatment factors, 73% germinated in the presence of GA; and equal numbers germinated between the light and the dark. The highest yielding treatment was the after-ripened fruit kept at

18/13°C in the light with the GA. Considering that all fruit were scarified and the overall low germination, dormancy must still be playing an important role. Only 2.6% of the total after-ripened sample germinated compared with <0.5% of the 'cold' treated sample.

Experiment 3. Following after-ripening for 24 months, germination increased to 29%, equally in the light and in the dark. Again all fruit were scarified, all had GA applied and all were kept at 14°C. Sixteen days after treatment, 31 fruit had germinated with 65% of these in the dark. Later germinations preferred the light. It appears that dormancy has been reduced to some extent and this is reflected in the increase in overall germination (increase from 2.6% to 29%) even though scarification and GA have been used as facilitators.

Experiment 4. It took 12 days until the first fruit germinated and by 70 days 7% had sprouted. Considering treatment factors on their own and only those that germinated, 93% had 1.0 mM GA added; 80% were in the light and 64% were scarified. The combination of GA and light yielded 73% of the germinated fruit. The treatments containing GA, light and scarified fruit produced 48% of the germinated fruit and the similar treatment with the unscarified fruit produced 25% of the total. These data indicate that after 30 months of storage at 25°C, raspweed fruits still exhibit a high degree of dormancy. The overall germination percentage was still low but has increased over that achieved in Experiments 1 and 2. In this experiment the application of GA was the major facilitator of germination. While scarification assisted, its affects across treatments were not as obvious. In this instance germination appeared to be influenced by light.

Implications. Field germination of raspweed is likely to be very low, probably as low as 1% for the fruit/seed bank. Fruits in the field are not kept in constant conditions and do not have growth promotants like GA freely available, nor are they readily scarified. It is obvious that raspweed fruits exhibit a very high degree of dormancy and or low viability. Viability has not been addressed and can not be ignored. Scarification to remove part of the woody pericarp may have enhanced germination but not to a great extent. This suggests that (a) some other non-mechanical agent is controlling dormancy and or (b) the seeds have low viability. The woody pericarp may not be a major barrier to germination. The assumption can be made that under field conditions the woody pericarp will eventually decay and with cool conditions the fruit will germinate on the soil surface and from depth. While light would not appear to be a major factor, preference for light conditions has been exhibited.

Cool temperatures around 15°C are much preferred for germination. In central Queensland, this would mean germination is restricted to the cooler winter months, but in southern regions, the germination window would be much wider. This temperature requirement may explain the limit of the species northern distribution. In central Queensland winter rains are quite rare so optimal conditions for germination are not likely to be experienced as often as they would in southern regions. However, raspweed is still a major problem in central Queensland, its weediness attributed more to its asexual reproductive traits.

Clearly, reproduction from seed is not raspweed's primary method of proliferation, but the plant devotes much energy toward it. This biological function must occur for a purpose. Maintenance of genetic variability, assurance of long term survival of the species and wider dispersal are the probable reasons. While raspweed's sexual reproductive strategies may not be as important as the asexual methods, they can not be disregarded when considering weed management techniques. Allowing the seed bank to replenish and build up, even if only 1% generate new plants, these new plants are then a potential problem considering the contribution they will make using their asexual reproductive strategies.

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COMPARATIVE BIOLOGY OF CRUCIFEROUS WEEDS: A PRELIMINARY STUDY

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Summary. Temperature and light responses of a number of crucifers were screened in the laboratory. Their developmental rates were also compared in a pot experiment. *Hirschfeldia incana* and *Sisymbrium officinale* showed a preference for light at almost all temperatures. However, several other species germinated best in the dark at lower temperatures and in the light at higher temperatures. *Hirschfeldia incana* took by far the longest to flower.

INTRODUCTION

Sixty nine species of Brassicaceae have become established in Australia, mostly from Europe. Thirty seven of these are considered as weeds by Auld and Medd (2). Despite their importance in agriculture and their significance in the naturalised flora, little is known of their biology and ecology. There are some exceptions to this statement. *Raphanus raphanistrum* and *Sinapis arvensis* have been studied widely overseas. As a major weed of the Australian wheat belt *R. raphanistrum* has received attention in respect of its control, seed bank dynamics, phenology and seed biology (3,4). *Sinapis arvensis* has similarly been studied in the northern hemisphere. There have been some studies of germination, competition with crops and herbicidal control of *Brassica tournefortii* (5). Even species causing major (but local) problems in cropping in Australia, such as *Rapistrum rugosum* and *Sisymbrium orientale*, or widespread weeds of pasture and roadsides, such as *Hirschfeldia incana*, remain virtually unstudied.

One of the most notable features of the introduced crucifers is the patchiness of their distributions (as can be seen from the maps in Flora of Australia, Volume 8). Even though some of the species have been introduced for over 150 years, it is likely that few have reached equilibrium in their distributions. Even the most abundant and widespread in cropping, *R. raphanistrum*, is believed to be still spreading. Within the climatically suitable regions, it is likely that abundance is affected by land-use and edaphic factors. For example, *S. arvensis* is most abundant in the northern hemisphere on heavy soils, neutral to alkaline, but it can occur on more acidic soils. Within Australia, *Rapistrum rugosum* in crops tends to occur on heavy, alkaline soils; its dominance as a weed in northern NSW and Southern Queensland may indicate a preference for higher temperatures and summer rainfall (though it also occurs as a weed in parts of South Australia). *Hirschfeldia incana* is one of the most common Brassicaceae on the southern tablelands of NSW, perhaps indicating a preference for cooler temperatures, higher rainfall and a dislike of cropping.

From published distribution maps, the current ranges of many weedy Brassicaceae appear to overlap little within New South Wales and within Australia as a whole. Indeed, it is seldom that more than one cruciferous weed is found in any crop. To what extent do their distributions reflect accidents of history, climatic adaptations or edaphic preferences? If we want to understand comparative distributions of species, we require comparative biological and ecological data. The experiments described here are part of a project to determine the extent to which soil pH and temperature responses are likely to affect crucifer distributions in Australia.

METHODS

Seeds of a range of species were collected throughout New South Wales in November 1990. They were stored in sealed containers in the laboratory. Due to limitations of space, only one source of seeds for most species was included in the study. In the pot experiment, two sources of *Brassica fruticulosa* and *Raphanus raphanistrum* were included. The study was of the nature of a preliminary screen; the data were not amenable to parametric statistical analysis.

Temperature and light response. Seeds were germinated in petri dishes at a range of temperatures, from 5°C to 35°C. There were three replicates of each species, both in the dark and in the light (12 hour photoperiod). Thirty seeds were placed in each petri dish, on top of two Whatman No.1. filter papers. Sufficient distilled water was added to fully moisten the papers. Periodically, further water was added as papers began to dry out. The species and their origins were as follows: *Brassica fruticulosa* (Port Botany); *B. tournefortii* (Hillston); *Sinapis arvensis* (Walgett); *Sisymbrium orientale* (unknown); *S. irio* (Quirindi); *S. officinale* (Denman); *S. erysimoides* (Hillston); *Hirschfeldia incana* (Gunning). Seeds of *Raphanus raphanistrum* remain in pod segments; in petri dishes they did not germinate and rotted. *B. tournefortii* did not germinate in water; seeds were pre-rinsed for ten minutes in 1% sodium hypochlorite to break dormancy. For the same reason *S. arvensis* were imbibed in 5ppm GA_3. Germination was recorded daily at high temperatures, less often at lower temperatures; seeds with at least their radicle or cotyledons visible were counted and removed.

Time to flowering. Seeds were sown on each of 5 dates: 16 April, 15 May, 4 July, 26 August, 30 September 1992. Seeds were planted in 15 cm pots at a depth of 0.5 cm (except for *S. orientale*, which were spread on the soil surface). There were 50 seeds in each pot. Following poor germination in April, seeds of *R. raphanistrum*, *B. fruticulosa* (Valley Heights only), *S. arvensis and B. tournefortii* were imbibed in 2ppm GA_3 overnight before later sowings. After emergence, seedlings were thinned to three per pot. For each sowing there were three replicates in a randomised complete block design. The same seed sources were used as before, with the addition of *B. fruticulosa* (Valley Heights), *R. raphanistrum* (Cobbitty and Rutherglen) and *Rapistrum rugosum* (Gunnedah). Every week the number of plants which had started to bolt and those which had begun to flower were counted.

RESULTS

Temperature and light response. Germination at optimal temperatures was good, with the exception of *S. irio* and *S. orientale* (Fig. 1). *H. incana* and *S. officinale* showed preferences for light throughout most of the temperature range. Most other species appeared to prefer light at the higher temperatures (*S. orientale*, *S. irio*, *S. erysimoides*, *S. arvensis*, *B. fruticulosa*); some species showed a distinct preference for darkness at lower temperatures (*B. tournefortii*, *S. erysimoides*, and possibly *S. orientale* and *S. irio*). Most species showed at least some germination at 5°C (the only exception was *S. officinale*). It was not possible from the daily counts to determine base temperatures (T_b) from the rates of germination. From Figure 1 it would appear that *S. officinale* may have a T_b of near 10°C, and *B. fruticulosa* may have the lowest T_b (based on the highest % germination at 5°C). In the light, several species appear to have base temperatures above 5°C (*S. arvensis*, *B. tournefortii*, *S. orientale*). *S. erysimoides* appears to have a T_b in the light over 10°C, but of below 5°C in the dark.

Time to flowering. For all sowing dates *H. incana* was the slowest to flower. The most rapid to flower for most sowing dates was *S. erysimoides*. *B. fruticulosa* and *R. raphanistrum* were also quick to flower from winter sowings. As would be expected, all species flowered quicker from spring sowings than from winter sowings. There was considerable mortality in the September sowing, following a period of high temperatures, hence data are not available for some species. Some species did not germinate well in the April sowing (see Methods); this was mostly due to dormancy, since emergence after imbibition in GA_3 was much better

Table 1. Time in days from 50% emergence to first flower on 50% of plants. Emergence was recorded to the nearest day, flowering to the nearest week.

Species	Sowing dates				
	16.4.92	15.5.92	4.7.92	26.8.92	30.9.92
B. fruticulosa (Valley Heights)	64	77	69	56	41
B. fruticulosa (Port Botany)	-	76	62	48	41
R. raphanistrum (Cobbitty)	(71)[a]	73	62	40	33
R. raphanistrum (Rutherglen)	-	73	69	48	41
Rapistrum rugosum (Gunnedah)	122	103	76	60	-
Sinapis arvensis (Walgett)	(95)	91	76	48	41
Sisymbrium officinale (Denman)	-	111	76	60	-
S. orientale (unknown)	(57)	99	75	54	47
S. irio (Quirindi)	-	90	55	60	-
S. erysimoides (Hillston)	-	70	48	34	49
Brassica tournefortii (Hillston)	(84)	85	69	68	-
Hirschfeldia incana (Gunning)	(190)	142	116	83	76

[a] Parentheses indicate small sample size.

Most species bolted some time before flowering began; however, *S. erysimoides* began to flower as it started to bolt. For most species bolting was fairly synchronous, whereas for *H. incana* there were sometimes differences of several weeks between individuals.

DISCUSSION

Greater germination of crucifers in the light than in the dark has been recorded for various species (eg 1). However, within a species the response to light can be variable, depending on the age of the seed and the duration of burial (e.g. *S. arvensis*). The two species most consistently showing a light preference across all temperatures, *H. incana* and *S. officinale*, often occur in pastures and not in tilled systems. Chearn (*pers. comm.*) found that *B. tournefortii* germinated best in the dark; Cousens *et al.* (unpublished) reported slightly higher germination in the dark for *R. rugosum*, but this became reduced with duration of storage. The response to light by the *B. tournefortii* in this study had clearly changed during seed storage. Up to

September 1991 there was virtually no germination in the light after bleach pre-treatment, and good germination in the dark (unpublished). Imbibition of *B. tournefortii* seeds with GA_3 in February 1991 resulted in good germination in both light and dark.

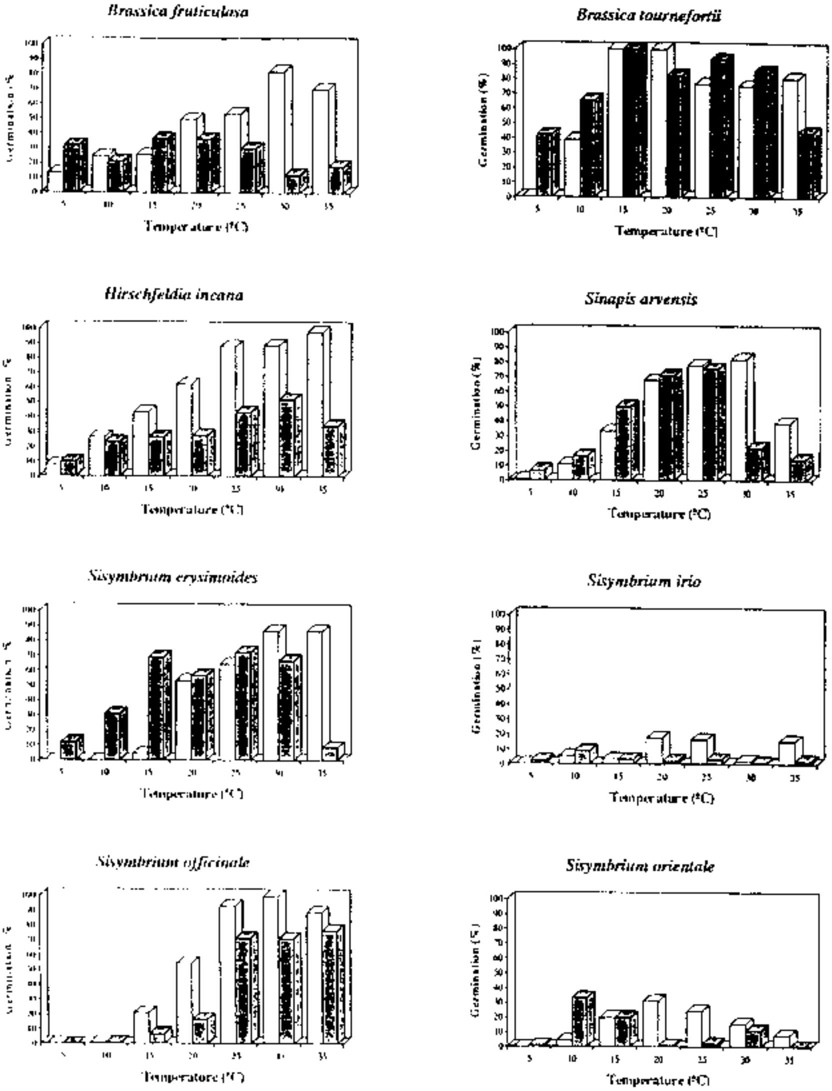

Figure 1. Germination in light/dark (stippled) and dark (shaded).

The length of time taken to flower has seldom been studied in crucifers. The most rapid development of 33 days for *R. raphanistrum* is somewhat less than the 49 days recorded by Cheam (3). However , soil temperatures in the pots are likely to have been higher than in the ground, perhaps leading to more rapid development. Because soil temperatures were not recorded, no attempt was made to compute any day degree requirements of the species (4). Time to flowering was notably longer for *H. incana* than for other species; for most sowing dates it took about twice as long as *R. raphanistrum* to flower. A species with a long developmental period is unlikely to succeed in an annual cropping system. By remaining as a rosette, it will suffer from competition with the crop for light. It may also be unable to reach maturity before the crop is harvested. This slow development may explain the predominance of this species in non-cropping areas.

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DIFFERENCES IN MORPHOLOGY AND SUSCEPTIBILITY TO HERBICIDES BETWEEN SEEDLINGS OF *BECKMANNIA SYZIGACHNE* AND *ALOPECURUS AEQUALIS* VAR. *AMURENSIS* IN WHEAT AND BARLEY CROPPING OF SOUTHERN JAPAN

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Summary. Seedlings of *B. syzigachne* and *A. aequalis* var. *amurensis* are difficult to distinguish because of morphological resemblance in their early growth stage in drained paddy fields for wheat and barley in southern Japan. Separating the two species is needed for the correct evaluation for efficiency of herbicides, since they differ in susceptibility to the preemergence application of trifluralin or benthiocarb + prometryn. Difference in color of roots was the most effective indicator to distinguish them.

INTRODUCTION

American sloughgrass, *Beckmannia syzigachne* Steud., has become a noxious gramineous weed in drained paddy fields for winter cropping of wheat, *Triticum aestivum* L., and barley, *Hordeum vulgare* L., in Kyusyu, southern Japan (2,4). Area affected by American sloughgrass was estimated as 30.9 percent against 58,544 ha of planted area in 1992, while short-awned foxtail, *Alopecurus aequalis* Sobol. var. *amurensis* (Komar.) Ohwi, affected 85.4 percent of the area. Close resemblance in the morphology of their young seedlings prevents the correct evaluation on the herbicidal efficiency to the two gramineous weeds. Therefore, distinguishable characteristics and susceptibility to some soil applied herbicides in American sloughgrass were investigated in comparison with short-awned foxtail.

METHODS

Differences in size of leaf blade. Seeds of American sloughgrass and short-awned foxtail were sown in a 5 cm of depth of sterilized light clay soil in the cement pots of 75 L, on 10 December 1990. Seedlings were grown under 4 different soil moisture rates. Size of leaf blade were measured on 73 days after seeding.

Morphological differences in seedlings and response to herbicides. In cement pot of 75 L filled with light clay soil, seeds of American sloughgrass and short-awned foxtail were sown into the surface soil with other species such as catchweed bedstraw, *Galium sprium L.* var. *echinospermon* Hayak, and so on. Seeds were stored under the ground in 80 cm for dormancy break during 50 days before seeding.

Wheat two-rowed and naked barley were sown in each one row in a pot. Details of the treatment of soil-applied herbicides are given in Table 1. Morphological characters were observed with the seedlings in 2 to 6 leaf stages collected from untreated plot at the end of March of both years. Herbicidal efficiency was evaluated through sampling the survived weeds at 122 days and 114 days after application in 1988 and 1989, respectively.

Table 1. Experimental design for herbicidal efficiency to *Beckmannia syzigachne* and *Alopecurus aequalis* var. *amurensis*.

Year	Seeding date	Plot no.	Herbicide			
			Name	Formulation	Rate (kg ai/ha)	Application date
1988	17 Nov.	1	benthiocarb + prometryn	emulsifier concentrate	4+0.4	18 Nov.
		2	benthiocarb + prometryn	granules	4+0.4	
		3	trifluralin	emulsifier concentrate	1.35	
1989	24 Nov.	1	benthiocarb + prometryn	granules	4+0.4	26 Nov.
		2	trifluralin	granules	1.13	

RESULTS AND DISCUSSION

Difference in leaf size. Length and width of leaf blade of the first, second and third leaves were given in Table 2. They were not affected by soil moisture rate in American sloughgrass, while the length of leaf blade of short-awned foxtail was inhibited under higher soil moisture rate. Width of leaf blade of American sloughgrass was significantly broader than that of short-awned foxtail in the second and third leaves, however they did not differ in length.

Table 2. Length (L) and width (W) of leaf blade (LB) of seedlings of *Beckmannia syzigachne* and *Alopecurus aequalis* var. *amurensis* under different soil moisture rates

Soil moisture rate[B]	*B. syzigachne*[A]						*A. aequalis* var. *amurensis*[A]					
	1st LB		2nd LB		3rd LB		1st LB		2nd LB		3rd LB	
	L	W	L	W	L	W	L	W	L	W	L	W
36.4%	24.9	0.8	26.0a	1.2	35.8a	2.2	19.9	0.7	29.9a	1.0	38.7a	1.7
37.1%	24.1	0.8	23.5a	1.3	41.0a	2.3	19.1	0.7	28.1a	1.0	38.0a	1.7
46.7%	21.5	0.8	29.3a	1.1	38.1a	2.1	21.4	0.7	30.0a	1.0	36.4a	1.8
51.7%	20.5	0.8	26.8a	1.2	39.1a	2.2	16.6	0.7	21.3b	1.0	29.8b	1.6

[A] Figures are mean value (mm) of 4 to 24 leaves for *B. syzigachne* and 17 to 31 leaves for *A. aequalis* var. *amurensis*. Same alphabet means no significant difference at 5% level by T-test.

[B] Mean of 3 measurements from January to February.

It is considered that the differences in width of leaf blade are too inconspicuous to adapt as a practical method for distinction of seedlings of both species.

Morphological differences in seedlings. Differences in some characters to distinguish the seedlings of american sloughgrass from short-awned foxtail were given in Table 3. Spikelet and husks at the base were effective for distinction if they remained. Young panicle in leaf sheath was also effective after initiated. The root color of American sloughgrass was white, while that of short-awned foxtail was pale reddish brown.

Table 3. Morphological differences in seedlings of *Beckmannia syzigachne* and *Alopecurus aequalis* var. *amurensis* in two- to six-leaf stage at end of March

Characters	*B. syzigachne*	*A.aequalis* var. *amurensis*
Spikelet and husks remained at end of mesocoytyle	glumes are swollen, floret is awnless	glumes are sharply flat and hairly, floret awned
Tip of ligule	minutely pointed	sharply pointed
Quality of leaf blade	minutely rough on surface	minutely rough only on margines
Young panicle in sheath	rachis-branch is obvious	rachis-branch is invisible
Root colour	white	pale reddish brown

Difference in root color is recognized as the most effective character among these for distinction, because it can be adaptable to the seedlings without spikelet and husks removed at sampling-time and before panicle initiation. The difference in root color was observed more clearly when half dried.

Response to preemergence application of soil-applied herbicides. Effects of preemergence treatment of soil-applied herbicides were given in Table 4. Through the herbicides treated and year, number of plants survived was greater in American sloughgrass than in short-awned foxtail with the difference in 4 to 40 percent of control. When herbicidal efficiency was evaluated without separating two species, it was resulted in overestimate for American sloughgrass, and in underestimate for short-awned foxtail.

Table 4. Effects of preemergence treatment of soil-applied herbicides to *Beckmannia syzigachne* and *Alopecurus aequalis* var. *amurensis* at 122 and 114 days after treatment as percent of untreated control

Year	Plot no.[A]	*B. syzigachne*		*A. aequalis* var. *amurensis*		*B. syzigachne* + *A. aequalis*	
		No. of plants	Air-dry weight	No. of plants	Air-dry weight	No. of plants	Air-dry weight
1988	1	33.0	-	5.8	-	20.7	-
	2	54.0	-	14.0	-	36.0	-
	3	5.8	-	1.2	-	3.9	-
Untreated control[B]		575	-	478	-	1050	-
1989	1	38.9	40.7	8.7	8.5	18.6	17.9
	2	19.5	35.5	13.6	22.6	15.5	26.4
Untreated control[B]		1656	18.6	3384	45.8	5040	64.4

[A] Refer Table 1.
[B] Number and g per m^2, mean of 2 replicates.

Characteristics in the emergence and seed germination of American sloughgrass have been reported (1). However, there was no effective method to identify the young seedlings of American sloughgrass (2,4), while mature plants could be distinguished without trouble from short-awned foxtail (3). In the experiments for evaluation of herbicidal efficiency to American sloughgrass and short-awned foxtail, following procedure has been adopted in order to decide the composition of the two species in sampled weeds. Individual seedling in border, which was marked before sampling time in middle March, was identified after its heading on few weeks after the time (4). The results of this study provide the simple and accurate method to separate the seedlings of American sloughgrass and short-awned foxtail. Difference in the response to some herbicides between the two species suggests a probable factor encouraging the infestation of American sloughgrass in winter cropping of wheat and barley in southern Japan.

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MORPHOLOGY AND DISTRIBUTION OF *AMMANNIA AURICULATA* WILLD. IN PADDY FIELDS OF SOUTHERN JAPAN

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Summary. *Ammannia auriculata* was detected as a new troublesome weed in paddy fields in Kyusyu islands beside two common species, *A. multiflora* and *A. coccinea*. The distribution range of *A. auriculata* was approximately similar to *A. coccinea* which naturalised in the 1950s. Morphological differences in peduncle, pedicel, seed and cotyledon were effective to distinguish *A. auriculata* from others.

INTRODUCTION

In recent years, *Ammannia* species have infested paddy fields of southern Japan, in spite of the application of newly developed herbicides. *Ammannia multiflora* Roxb. and *A. coccinea* Rottb., a naturalised species, had been known as common *Ammannia* species in Japan. Recently, we found out that another naturalised species, *A. auriculata* Willd. had been incorrectly identified as *A. coccinea* in paddy fields in Kyusyu islands, located at southern Japan (3). *A. auriculata* was first recorded in Japan by Hatsushima (2) in 1978. *A. auriculata* has been incorrectly identified as *A. coccinea* because of their morphological resemblance. Distribution and morphological differences of *A. auriculata* were investigated and compared with 2 other *Ammannia* weeds.

METHODS

Distribution in Kyusyu islands. The district of an agricultural extension office was taken for the surveying unit and 58 of 106 units were surveyed in this study. The occurrence of *A. auriculata* and *A. coccinea* were surveyed in fallow paddy fields or paddy rice fields with no autumn ploughing in the units. The survey was carried out from January to March and from November to December in 1992.

Morphological characteristics. To investigate morphology of mature plants of *A. auriculata*, *A. coccinea* and *A. multiflora*, specimens collected from paddy fields in Kyusyu and the Nile delta of Egypt, and fresh plants growing in Kyusyu National Agricultural Experiment Station, were examined.

Seeds of three *Ammannia* species were collected from mature plants growing in paddy fields in the Experiment Station in late autumn to early winter in 1991. They were dried and kept in a desiccator at room temperature.

Seed surface was observed with a scanning electron microscope (HITACHI 450-LB). Size of twenty seeds was measured with a micrometer under a stereoscopic microscope. Fifty seeds were weighted with five replications. To investigate morphology of seedlings, seeds of the three species were seeded on watered paddy soil in plastic cases (18x13 cm, depth 6 cm) at a spacing of 1.5x1.5 cm. Nutrients were applied at rates of 30-30 g a.i. ha N-P_2O_5-K_2O in a compound fertiliser. The cases were incubated in a growth chamber at 30°C, 14 h light at 18,000 lux. Cotyledons were observed under a stereoscopic microscope periodically.

RESULTS AND DISCUSSION

Distribution in Kyusyu islands. The results of the survey on the occurrence of *A. auriculata* and *A. coccinea* are shown in Table 1. *A. auriculata* was observed in 31 of 58 surveying units while *A. coccinea* was observed in 24 (Table 1). *A. auriculata* has widely infested Kyusyu already, at a higher frequency than *A. coccinea* which become naturalised in Kyusyu in the 1950s (1).

Table 1. Frequency in occurrence of *A. auriculata* and *A. coccinea* in districts of agricultural extension offices in Kyusyu islands

	Investigated (A)	Observed (B)	Frequency (B/A)
A. auriculata	58	31	0.53
A. coccinea	58	24	0.41

In the survey, *A. auriculata* and *A. coccinea* were often observed in the same field. Considering this phenomena and the morphological resemblance, there is a possibility that *A. auriculata* will be observed in regions infested with *A. coccinea* beside Kyusyu islands. Therefore, infestation with *A. auriculata* should be noticed in such regions.

Morphological characteristics. The morphological characteristics of three *Ammannia* species are summarised in Table 2. In mature plants, *A. auriculata* could be easily distinguished from *A. multiflora* by the remarkable pinkish-purple or purple petals and larger diameter capsules. Since *A. auriculata* and *A. coccinea* resembled each other in shape and colour of petals and size of capsules. The length of peduncles and pedicels were te most reliable indicators for distinguishing *A. auriculata* from *A. coccinea*.

The seed surface was comparatively smooth in *A. auriculata*, while it was rough in the other two species. This difference can be seen with the naked eye as a practised observer. Since the most remarkable characteristic in seeds of *A. auriculata* was its surface, it is considered the most useful and reliable key for distinguishing seed of *A. auriculata* from others.

Since cotyledons of *Ammannia* species change in size and shape with extension, to distinguish species the shape of cotyledons should be compared at the same stage. Cotyledons of *A. auriculata* had remarkable processes on their edge until the middle phase of extension, while cotyledons of the other two species lost these processes soon after germination. The processes on cotyledons of *A. auriculata* were the most reliable characteristics for distinguishing the *Ammannia* species in the cotyledon stage.

The results of this study can be used as helpful information in ecological study on *Ammannia* species.

Table 2. Key to differentiating three weed species of *Ammannia* in Kyusyu islands

	A. auriculata	*A. coccinea*	*A. multiflora*
Mature plants			
Basal part of leaf on flowering stem	auriculate, amplexicaul to winged stem	auriculate, amplexicaul to winged stem	truncate or auriculate slightly to ridged stem
Petals	4 petals, 2-3 mm long, pinkish-purple or purple	4 petals, 2-3 mm long, pinkish-purple or	4 petals, 0.5 mm long, minute
Peduncles	3-10 mm	0-2 mm	0-3 mm
Pedicels	2-5 mm	0-1 mm	0-1 mm
Mature capsules	2-3.5 mm in diameter, exceeding floral tube	3-4 mm in diameter, exceeding floral tube slightly	2-2.5 mm in diameter, exceeding floral tube by >50%
Seeds			
Colour	lustrous light brown	yellowish brown	reddish brown
Length (mm)	0.44 (0.042)*	0.47 (0.031)	0.38 (0.030)
Width (mm)	0.41 (0.048)	0.39 (0.036)	0.30 (0.028)
Thousand seed weight (mg)	19.3 (0.17)	21.2 (0.28)	12.3 (0.21)
Surface	comparatively smooth	rough	rough
Cotyledon			
Basal part	cuneate in early stage, ovate later	ovate	cuneate in early stage, ovate later
Processes on edge	remarkable till middle phase	indistinct	indistinct

* Standard deviations for length, width and weight of seeds showed in parenthesis.

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ASSESSMENT OF THE ORIGINS OF *TRIBULUS TERRESTRIS* IN AUSTRALIA

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Summary. *Tribulus terrestris* is an introduced weed of unknown origin in Australia. It is a problem to the Australian dried fruit industry and is toxic to livestock. Correct identification of the weed is important because several native forms of *Tribulus* are confused with *T. terrestris*. Isozyme analysis separated seven Australian and six overseas populations of *T. terrestris* into four groups. The southern Australian, Broome (northern Western Australia), South African and U.S.A. populations formed a close group. Goomalling (southern Western Australia), Middle East and Crete populations formed a second group. The Indian population was separate from other groups and the Queensland and Northern Territory populations were closely related to each other. This preliminary analysis points to a foreign origin for weedy populations of *T. terrestris* in southern Australia.

INTRODUCTION

Tribulus terrestris (Zygophyllaceae) (caltrop) occurs in semi-arid and Mediterranean-type climates world-wide. It is a prostrate, summer growing annual. The seeds germinate after late spring and summer rains in warm conditions (24 - 27°C). The fruit consists of a woody burr comprised of five wedge-shaped cocci each with one or two pairs of large spines (8). There are 2 to 4 seeds per coccus (16). Seeds can remain viable for many years if buried in the soil, thus after successive generations a large reservoir of seed can accumulate (16).

Weedy populations of *T. terrestris* are found in many locations in Australia (10, 16). It is thought to have been accidentally introduced to New South Wales before 1895 (16). *Tribulus terrestris* is a problem to the Australian dried fruit industry because the spiny burrs may contaminate harvested dried fruit (7). Additionally the plant can be toxic to livestock, especially sheep. (2, 3). The taxonomic status of *T. terrestris* is unclear (2, 10, 12 19) and forms of the plant are variously considered to be native or introduced. Before considering biological control of this weed, it is essential to identify the introduced weedy form of *T. terrestris* and to determine its overseas origin (12). Here we report on a preliminary analysis, using isozyme techniques, to aid the identification of forms of *T. terrestris* as an indication of their geographic origin.

MATERIALS AND METHODS

Tribulus terrestris accessions were obtained by written requests to potential collectors. Over 80 samples were received from mainland Australia, and 13 from overseas locations with Mediterranean-type climates. The analysis presented here used seven populations from Australia and six from overseas. Dry seeds were stored at room temperature until needed. Seeds were excised from the woody burr and dipped in 1.25% sodium hypochlorite for 5 minutes, then washed in distilled water. The seeds were germinated on moist filter paper in a sealed petri dish incubated at a 16 hour 20°C, 8 hr 35°C cycle. Seedlings were used for isozyme work when they were 2 to 4 days old.

Cotyledon and root tip tissue of each seedling were homogenised together in 7 µL of 0.16M phosphate buffer (pH 7.0), containing 2.5% sucrose, 0.12% bromophenol blue and 0.75 mg mL^{-1}

dithiothreitol, in a plastic microwell tray on an ice bath (9). Three 2 x 4 mm filter paper wicks were placed in each sample. Five to ten seedlings from each of three plants was assayed for each population, except for Crete where seeds from only one plant was available.

Horizontal starch gels were made from 9.6% hydrolysed starch (Connaught) in each of three different buffer systems. Three enzymes were assayed on each of three buffer systems as follows: histidine gels at pH 8.0 (4), phosphoglucomutase (PGM) EC 2.7.5.1, 6-phosphogluconate dehydrogenase (6PGD) EC 1.1.1.44, phosphoglucoisomerase (PGI) EC 5.3.1.9; tris-citrate gels at pH 7.0 (11), aconitase (AC) EC 4.2.1.3, isocitrate dehydrogenase (IDH) EC 1.1.1.42, malate dehydrogenase (MDH) EC 1.1.1.37; lithium borate gels at pH 8.0 (9), esterase (EST) EC 3.1.1.1, leucine aminopeptidase (LAP) EC 3.4.11 or 13, glutamate-oxaloacetate transaminase (GOT) EC 2.6.1.1.

A wick from each sample was inserted into a slot cut in the cathodal side of each gel. To prevent the gels overheating, electrophoresis was carried out at 4°C in a refrigerator with an ice bath placed over each gel and a maximum current of 50 mA. Electrophoresis was terminated when the bromophenol blue front had moved about 10 cm. Each gel was sliced horizontally into 3 sections and each slice stained for an individual enzyme.

The assay methods used for EST, IDH and PGM and LAP were those described by Shaw and Prasad (13), except that an agar overlay was used for PGM. PGI, AC and MDH assays followed the methods of Richardson *et al.* (11), and 6PGD and GOT the method of Brown *et al.* (5). Stained gels were fixed with acetic acid, then rinsed in water, wrapped in plastic and photocopied for a permanent record. Isozyme banding patterns were scored immediately after staining.

Cluster analysis was performed using the UPGMA method (14) with modified Rogers distance (20) on the Biosys-1 computer program (17).

RESULTS AND DISCUSSION

Six of the enzymes with a total of eleven polymorphic loci were used in the analysis. In GOT and LAP systems the resolution proved too poor to score confidently, so they were excluded. PGI loci were clearly polymorphic, but were also excluded because they expressed complex zymograms with multiple overlapping bands. This indicates that there are more than the expected two loci for PGI (18), possibly with heteropolymers between the loci. It is therefore likely that the populations examined were polyploid. Additionally, fixed heterozygosity at the 6PGD - 2 locus in all populations examined, plus preliminary chromosome counts (4n = 24) support this view. Only those enzymes that demonstrated a diploid-like expression for the polymorphic loci examined were used in the analysis.

The dendrogram (Fig. 1) shows that some of the populations are very similar to each other. The southern Australian, Broome (northern Western Australia), South African and U.S.A. populations formed a close group. Goomalling (southern Western Australia), Middle East and Crete populations formed a second group. The Indian population was separate from any other groups and the Queensland and Northern Territory populations are closely related to each other, but were the greatest distance from the other populations. The percentage standard deviation of the best fitting dendrogram was 15.3% (6). Other methods used to derive genetic distances (17) produced essentially the same overall dendrogram.

This preliminary analysis supports the view that there are two forms of *T. terrestris* in Australia, an introduced form and a native form. The form found mainly in southern Australia is very similar to the plants from some of the overseas collections. The Northern Territory and Queensland forms of *T. terrestris* had the greatest genetic distance from overseas populations indicating that they are native to Australia. Possible origins of the introduced form of *T. terrestris* are the Mediterranean, Middle East and South Africa. The inclusion of further samples and cytogenetic data in the analysis will help to clarify the likely origins of the introduced *T. terrestris*.

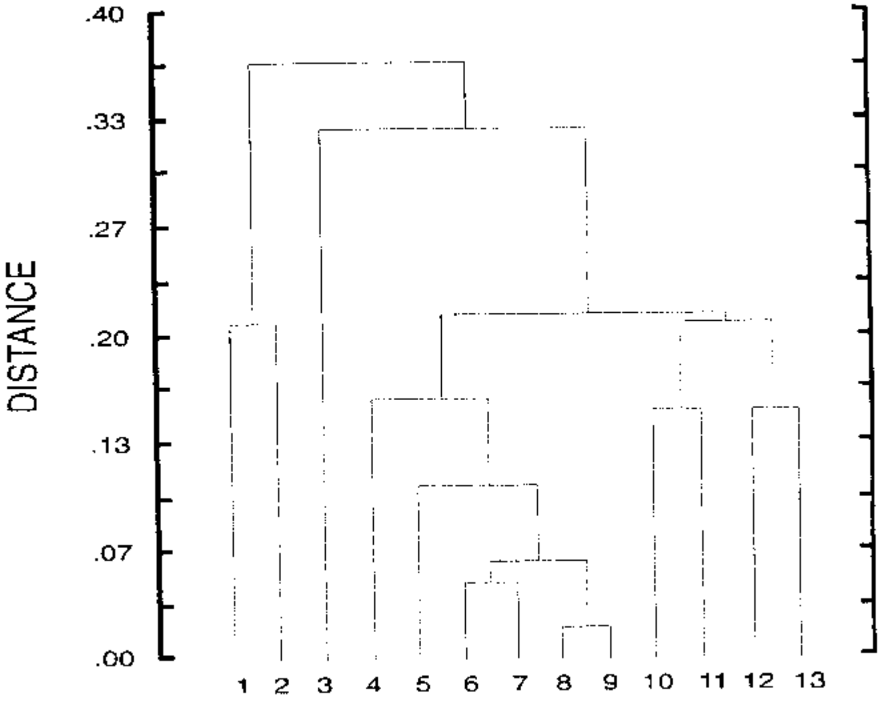

Figure 1. Dendrogram showing relationships among *Tribulus terrestris* populations, based on isozyme dissimilarity. Populations are as follows: (1) Darwin, Northern Territory, (2) Charters Towers, Queensland, (3) Kashmir, India, (4) Rondebosch, South Africa, (5) Loxton, South Australia, (6) Mudgee, New South Wales, (7) Mildura, Victoria, (8) Prosser, WA, USA, (9) Broome, Western Australia, (10) Crete (11) Kuwait City, Kuwait, (12) Tehran, Iran, and (13) Goomalling, Western Australia.

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VARIATION IN LEAF FORM AND FLOWERING PERIOD OF CAPEWEED *(ARCTOTHECA CALENDULA)*

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Summary. A total of 332 specimens of capeweed from major Australian herbaria, comprising 578 separate plants, were examined in an investigation of leaf-form variation and flowering period across the continent. The degree of leaf incision ranged from almost entire margins to highly dissected leaves and was not related to habitat or land use. The incidence of leaf-form types varied significantly among States, suggesting that at least three separate introductions of capeweed occurred in Western Australia, South Australia and New South Wales. Over 97% of the plants in this study were flowering when collected, and specimens were located in flower in every month of the year although the majority occurred in the latter half of the year. The relationship between collection date and latitude was significant with later collections in more southerly locations.

INTRODUCTION

The ability to predict in advance which plant species are likely to pose weed problems when introduced to a new environment remains an elusive goal for weed scientists. With a few notable exceptions (1, 2), the history of introduction and spread of existing weeds is one source of information to which little attention has been paid (3). Plant specimens preserved in herbaria provide a readily available source of historical information about introduction patterns, rates of spread, changes in morphology over time and other aspects of the biology and ecology of the species. This paper is part of a larger study of capeweed introduction and spread in Australia based on herbarium specimens and other historical sources (Wood, unpublished data).

METHODS

Herbarium specimens of capeweed from the following herbaria were examined: the State Herbarium of South Australia, the Queensland Herbarium, the Tasmanian Herbarium, the Western Australian Herbarium and the Australian National Herbaria in Canberra, Melbourne and Sydney. All 332 specimens collected prior to 1985 were examined and for each specimen the date, location of collection and collector's comments (if any) were recorded, and the latitude and longitude of each location was determined where possible; not all information was available for every specimen. Only four specimens were collected from the Northern Territory and these were not included in the analyses described in this paper. Some specimens consisted of several plants on a single sheet and for each of the 578 plants the flowering status and leaf form were also recorded where possible.

Leaf form was scored in three subjective categories: relatively smooth leaf margin (designated as type A), moderately incised leaf margin (type B) and highly incised leaf margin (type C). The type C leaf form was the least common and for some analyses types B and C were combined to yield an adequate sample size. Information about the habitat and land use at the collection site was available for 146 plants; the categories used in the analysis were disturbed ground (including roadsides), urban areas, agricultural land and others. Insufficient data were available to analyse cultivation and grassland separately. Data were analysed using G-tests for equality of proportions (4) and the 0.1% significance level was used throughout.

RESULTS AND DISCUSSION

Leaf form. A significant difference in leaf form among States was observed (Table 1). Over 95% of plants collected in SA and Tas were type A, and Type C plants were virtually absent. By contrast over 44% of plants collected in NSW (including ACT) were types B and C, and other States had intermediate leaf form patterns. There was no relationship between leaf form and either latitude or land use at the site of collection.

Table 1. Summary of plant collection data by State

State	WA	SA	NSW[a]	Vic	Qld	Tas
Number of plants	62	263	93	59	58	43
Type A (%)	68.3	96.5	55.4	65.5	64.3	95.2
Type B (%)	26.7	3.5	38.6	31.0	28.6	2.4
Type C (%)	5.0	0	6.0	3.4	7.1	2.4
(n)	(60)	(260)	(83)	(58)	(56)	(42)
Flowering (%)	96.7	96.9	98.9	94.7	96.2	100
Flowering in						
Jan-Mar (%)	0	0.4	0	12.5	0	14.6
Apr-June (%)	1.9	0.8	1.1	6.3	0	2.4
July-Sept (%)	65.4	40.6	88.9	22.9	62.0	17.1
Oct-Dec (%)	32.7	58.2	10.0	58.3	38.0	65.9

[a] Includes ACT

The variation among States is probably the result of separate introductions of capeweed with differing leaf forms. The earliest recorded collections of capeweed in Australia date from the 1830s in WA, followed by SA in the 1840s and NSW in 1865 (Wood, unpublished data). The populations in southern Qld were probably derived from a northward expansion from NSW, while the pattern of introduction into Vic and Tas is less clear. It is intriguing to speculate that the dissected-leaf form may have been better adapted to the more humid climate of the east coast than the smooth-margined form. A survey of the current distribution of capeweed leaf forms in NSW is planned for 1994.

The proportion of type A plants collected has increased significantly over time, however this may be attributable to the preponderance of SA specimens collected in the recent past; about 45% of all plants were collected in SA and of these 81% were collected after 1964. When data from individual states (SA and NSW) were analysed separately there was no change in leaf form incidence over time, but data sets may have been too small to detect trends.

Flowering. Overall 97% of all plants collected were in flower; this percentage did not vary significantly among States (Table 1). Plants in flower were collected in all months of the year, but almost all collections (97%) occurred in the second half of the year. Collection month was significantly related to latitude (Table 2) with flowering plants collected later at more southerly latitudes.

While this observation is not conclusive evidence of a later flowering season with increasing latitude (it is possible that, for a variety of reasons, collection activity in more southerly locations increases towards the end of the year), variation in flowering season with latitude due to photoperiodic effects is well known (5) and this is the most likely explanation. The significant difference in collection incidence among the States (Table 1) is most probably a reflection of the latitude effect.

Table 2. Relationship between collection month and latitude of capeweed specimens collected in flower. Values are percent plants from each latitude range collected in each quarter.

Latitude (°S)	(n)	Jan-Mar	Apr-June	July-Sept	Oct-Dec
<30	(70)	0	0	60.0	40.0
30-34	(261)	0.4	0.4	48.3	51.0
35-39	(149)	4.0	0	40.3	55.7
40+	(40)	15.0	0	17.5	67.5

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LATITUDINAL DIFFERENTIATION IN HEADING PHOTOPERIOD SENSITIVITY AND SEED DORMANCY OF *ECHINOCHLOA ORYZICOLA*, AN OBLIGATE WEED IN FLOODED RICE

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Summary. Latitudinal differentiation in heading photoperiod sensitivity and seed dormancy of *Echinochloa oryzicola*, an obligate weed in flooded rice, was studied by treating plants of the strains from seven countries with 8, 12 and 16 h photoperiod, and by submerging seeds in water at 4°C. Strains from countries in lower latitudes such as Sri Lanka, Bangladesh and Taiwan headed even under 16 h photoperiod and were identified as having weak photoperiod sensitivity. Strains from countries in higher latitudes had strong photoperiod sensitivity and did not head under the long photoperiod, except for a strain from northern Japan which was weakly photoperiod sensitive. Seeds of strains from Sri Lanka and Bangladesh showed more than 30% germination after 38 days of submergence, but strains from higher latitudes had a stronger dormancy and exhibited little germination after submergence. The significance of latitudinal differentiation in heading photoperiod sensitivity and strength of seed dormancy are discussed with respect to survival strategies of this obligate weed in flooded rice.

INTRODUCTION

Echinochloa oryzicola Vasing. (= *E. phyllopogon* Stapf) is an obligate weed in flooded rice and is widely distributed over temperate and tropical regions of the world (1,3,6,9). It has various characters adaptive as a weed in flooded rice, including its morphological mimicry to rice (1,9), anaerobic seed germinability in flooded soil (4,5,7,9,12), dormancy-germination pattern of soil-buried seeds synchronizing to soil condition in the crop (7,12).

Moreover, *E. oryzicola* is well known to exhibit a geographical cline in heading time in Japan (8,9,10). Heading time of the weed as well as that of rice becomes earlier as the latitude increases, and the time when a local population of the weed initiates heading coincides the heading time of the rice cultivar planted. The coincidence of heading times between crop and weed is an important survival strategy for the weed to escape from hand weeding. Objectives of the experiments reported herein were to study latitudinal differentiation of *E. oryzicola* in heading photoperiod sensitivity and strength of seed dormancy in 12 strains originating in several temperate and tropical countries.

METHODS

Plant materials. Seeds of 12 strains of *E. oryzicola* supplied by Drs. N. U. Ahmed, L. S. Leu, S. Matsunaka and T. Yabuno were planted in mid July at our experimental field in Kyoto under a natural day length and their identities were confirmed according to Yabuno (9).

Photoperiod sensitivity in heading. Germinating seeds of each strain at 25°C were planted in late July in 1/5,000 are pot and thinned to 3 plants per pot with three replications. They were treated with 8, 12 and 16 h photoperiods in three identical growth chambers at 25°C and 70% relative humidity. Natural day length exceeded 9 h during the experimental period until mid November.

Then, only natural light was used for the 8 h treatment (7:00-15:00). Both natural light and supplemental light (177 µmol/sec/m^2) were used for the 12 and 16 h treatments.

Depth of seed dormancy. Plants of each strain were grown under a natural day length in Kyoto. The plants headed from late July to mid September, depending on the strain. Seeds maturing within a month after initial heading were collected, air-dried for 10 days under a room condition, and stored with silica gels at -21°C for maintenance of seed dormancy. Submergence was initiated in late December by placing 20 seeds into a 20 mL bottle with 3 mL of distilled water at 4°C in the dark. Germination of the submerged seeds were periodically tested at 30°C in the light, and the percentages were used as a criterion for the strength of seed dormancy. The experiment was conducted with three replications.

RESULTS AND DISCUSSION

Photoperiod sensitivity in heading. All of the strains of *E. oryzicola* used appeared to be short day plants. They had an optimum photoperiod for heading at either 8 or 12 h, with heading delayed or prevented at the 16 h photoperiod (Table 1). Strains which headed at 16 h were those from Sri Lanka, Bangladesh, Taiwan and Kamikawa (Japan). There was a negative correlation between the latitudes of original collection sites and the duration from planting to heading under a photoperiod at 12 h ($r=-0.823$, $n=11$, $P=0.01$).

The photoperiod sensitivity of rice cultivars is often determined by the durations of basic vegetative phase (BVP) and photoperiod sensitive phase (PSP), as described elsewhere (13,14). We arbitrarily adopted this concept and calculated the BVP and PSP for each strain of *E. oryzicola* (Table 1). Strains from lower latitudes such as Sri Lanka, Bangladesh and Taiwan had BVP values from 16 to 24 days and PSP from 27 to 36 days, and headed even under the 16 h photoperiod
But strains from higher latitudes such as France, China and Japan had smaller BVP and did not show heading at 16 h, though the one from Kamikawa, Hokkaido District of Japan, showed smaller BVP and greater PSP values as well as heading at 16 h. We classified strains into two groups with weak and strong photoperiod sensitivity in heading. The weakly sensitive strains include those from Sri Lanka, Bangladesh, Taiwan and Kamikawa, whereas the strongly sensitive strains include the ones from France, China, Korea and Japan except the one from Kamikawa.

Seed dormancy. The strength of seed dormancy of *E. oryzicola* was compared among strains by determining germination percentages of the seeds submerged in water at 4°C. Seeds of the two Sri Lanka strains exhibited low germination percentages before submergence and more than 30% germination after 34 days (Table 2). Much greater germination was obtained for seeds of Bangladesh strain with the same duration. Seeds of strains from latitudes at higher than N 30° germinated little before 34 days and reached 50% at either 68 or 111 days. There were negative correlations between the latitudes where strains originated and the germination percentages at 68 days ($r=-0.672$, $n=12$, $P=0.05$). Therefore, we concluded that the strength of seed dormancy increased with latitude in the northern hemisphere.

Table 1. Heading photoperiod sensitivity of various strains of *Echinochloa oryzicola* Vasing

Country	Collection site	Latitude N°	Photoperiod (hr)[a]			BVP[b]	PSP[b]
			8	12	16		
Sri Lanka (13)	Angunawala	8	ND[c]	ND	ND		
Sri Lanka (11)	Gampola	8	45.7	71.2	81.6	20.7	35.9
Bangladesh	Dacca	24	41.2	53.3	68.6	16.2	27.4
Taiwan	Tauyuen	26	49.3	49.3	78.6	24.3	29.3
Korea	Fuyou	36	34.5	35.9		9.5	100+
China	Beijing	40	32.7	35.7		7.7	100+
France	Camargue	47	35.2	33.4		8.4	100+
Japan	Kagoshima	32	36.8	31.9		6.9	100+
Japan	Nagasaki	33	37.4	31.9		6.9	100+
Japan	Takatsuki	35	43.1	56.7		18.1	100+
Japan	Konosu	36	37.5	35.2		10.2	100+
Japan	Kamikawa	44	29.7	29.7	76.8	4.7	47.1

[a] The values shown are the mean numbers of days after planting with three replications. Standard errors of the means were smaller than 2.0.

[b] The BVP and PSP are the duration of the basic vegetative and photo sensitive phases in days.

[c] Not determined.

Table 2. Germination percentages of the seeds submerged in water at 4°C

Country	Latitude N°	Germination percentage after submergence[a]				
		0	34	68	111	161
Sri Lanka (13)	8	7.5	31.7	79.3	51.7	85.9
Sri Lanka (11)	8	2.5	36.7	71.7	59.5	91.1
Bangladesh	24	51.0	87.3	94.0	24.0	25.6
Taiwan	26	0.0	4.0	39.0	89.0	98.0
Korea	36	0.0	2.0	11.7	25.2	63.8
China	40	0.0	2.0	48.7	89.2	96.3
France	47	2.0	1.3	25.0	70.3	94.3
Japan (Kagoshima)	32	1.0	6.7	45.0	48.3	70.2
Japan (Nagasaki)	33	3.0	1.7	37.0	44.8	50.8
Japan (Takatsuki)	35	7.5	6.7	32.3	39.1	40.4
Japan (Konosu)	36	0.0	0.7	3.3	5.3	50.5
Japan (Kamikawa)	44	1.0	16.7	44.7	49.6	55.3
L.S.D. (0.05)		7.9	11.1	28.3	22.7	14.8

[a] Germination percentages at 30°C for 7 days in the light after the days of submergence indicated.

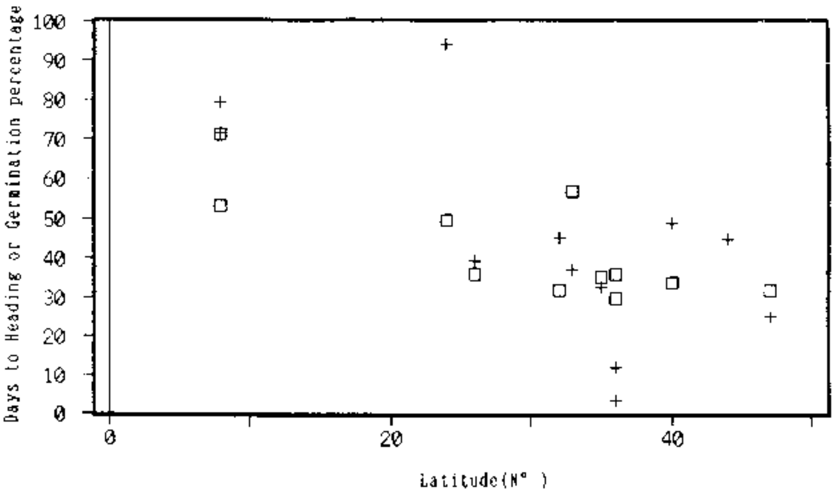

Figure 1. Interrelationship of the heading photoperiod sensitivity at 12 hr (?) and the germination percentages after submergence for 68 days (+) with latitudes of the strains originated.

Photoperiod sensitivity of the rice cultivar planted in a given region is an important determinant to ensure full development and yield from water and temperature stresses at heading and maturity. In most of tropical Asia, rice cultivars traditionally planted had a strong photoperiod sensitivity with heading time coinciding with end of the wet season. But there has been a pronounced reduction in the sensitivity since the extent of irrigation has grown along with the extension of newly bred cultivars since the 1960's (2). The cultivars planted in the northern region of Japan are weaker in photoperiod sensitivity than those planted in the southern region (15). Photoperiod sensitivity of *E. oryzicola* strains used here appears to be in agreement with the sensitivity of rice cultivars where each strain of the weed originated. The strains from France and Kamikawa were classified to be strong and weak in the sensitivity, respectively, though the two collection cites are little different in latitude (Table 1). This is probably related to far higher temperatures in the fall in Camargue. *E. oryzicola* is an obligate weed found exclusively in flooded rice and escapes from hand weeding by means of morphological mimicry before heading (1,9). Yabuno (9) previously pointed out the importance of hand weeding as a selection pressure by verifying a parallel geographic differentiation of Japanese strains in heading time to those of rice.

Seed dormancy is also a significant character for a weed to survive through hostile winter temperatures in a region of high latitude. The weed tended to have stronger seed dormancy in temperate regions. Strains from tropical Asia, where germination temperatures prevail throughout the year, had weaker seed dormancy. In such regions the seeds produced may germinate relatively soon after maturity, with weed infesting fields of flooded rice when water becomes available for germination. Further experiments with a greater number of strains from locations within and between countries and field observation will be required to verify the survival strategies in heading photoperiod sensitivity and strength of seed dormancy of this weed in flooded rice.

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EFFECT OF APPLICATION TIME OF TWO SELECTIVE HERBICIDES ON PANICLE AND SEED PRODUCTION OF WILD OATS (*AVENA* SPP.)

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Summary. The effect of time of herbicide application on the fecundity of wild oats was examined in a glasshouse experiment as part of a program to evaluate the potential for selective spray-topping in wheat. Seven times of spraying were studied on wild oat plants ranging in growth stages from late tillering to early panicle emergence. Two herbicides, fenoxaprop-ethyl and flamprop-methyl were applied at 17.25 and 225 g ai/ha respectively. Wild oat seed production was reduced by between 64 and 99.9% and panicle control ranged from a 10% increase to 99% reduction. Results confirmed that early application (late tillering) is optimal in terms of plant kill and seedset reduction but late applications (early boot) still have value in reducing seedset, which might be useful for controlling wild oat populations on a long term basis.

INTRODUCTION

Simulation modelling of wild oat control strategies by Medd and Pandey (3) indicated that a reduction in seedset/seed rain of greater than 70% over and above that achieved by normal herbicide applications could be justified economically. Under conditions where populations were increasing, 70% control of seed input to the seed bank returned a small monetary loss with an expected crop yield of 1.5 t/ha. The tactic became profitable following increases in either crop yield or seed kill efficiency. If this tactic could be developed commercially, it has potential to improve the effectiveness of wild oat control in wheat and other crops, thereby reducing both the overall cost and volume of herbicide used in the long term.

Preliminary field experiments indicated that the late application of herbicides for wild oat control in wheat has potential for reducing seed production by up to 96% (2). The experiments showed that fenoxaprop-ethyl and flamprop-methyl were far more effective for late application than diclofop-methyl or tralkoxydim. Medd *et al.* (2) suggested the term 'selective spray-topping' to describe the use of selective herbicides applied late post emergence with the aim of reducing seed production.

In order to examine the relationship between application time and reduction in wild oat seedset, a glasshouse experiment was undertaken using the two most promising herbicides, applied over a range of times from late tillering to early panicle emergence.

METHODS

A glasshouse experiment was conducted at the Agricultural Research and Advisory Station, Glen Innes, to examine the effect of two herbicides at seven times of application on seedset in wild oats. The growth stage of every tiller on each plant was recorded using Zadok's scale (4). Herbicides were applied to ten single plant replicates at each time of application. Fenoxaprop-ethyl and flamprop-methyl were applied at half the minimum labelled rates (17.25 and 225 g/ha respectively). Ten pots were also used as unsprayed controls. Temperatures and relative humidities at the time of spraying are given in Table 1 for each time of spraying.

Wild oat seeds were planted on 8 August 1992 into black plastic pots (15 cm diameter) filled with a sand/loam/peat mixture. Seedlings were thinned to one per pot between 8 and 20 days after sowing. Pots were watered by hand immediately after sowing and by an automatic overhead sprinkler system twice daily thereafter. Ammonium nitrate was applied on 10 September 1992. Pots to be treated were removed, sprayed, then returned the glasshouse. Herbicides were applied through a three metre hand held boom fitted with 8003 Teejet® flat fan nozzles (spaced 50 cm apart) at 240 kPa and spray volume 189 L/ha.

Regular assessments included visual scoring of plant damage and tiller/panicle counts. Panicles were harvested as they ripened and before the commencement of seed shedding. A zero to five score was used to visually rank panicle/seed control (zero = no control and five = 100% control). Scores above three are considered commercially acceptable which corresponds to at least 80% control (1). Post harvest measurements were glume counts and filled seed counts per plant.

Table 1. Wild oat growth stages and spraying conditions at the time of application.

Application time	1	2	3	4	5	6	7
Spraying details							
Date of spraying	27.9.92	2.10.92	6.10.92	13.10.92	19.10.92	26.10.92	30.10.92
Days after first spray	0	5	9	9	22	29	33
Temperature (°C)	17	18	19	19	15	21	20
Humidity (%)	41	38	54	62	54	39	58
Wild oat growth stage for fenoxaprop-ethyl pots[1]							
Tillers/plant	12.6	13.0	14.3	14.5	15.4	19.6	16.6
Tillers - vegetative (%)	100	100	100	81	43	33	17
Tillers - elongating (%)	0	0	0	28	56	48	52
Tillers - booting (%)	0	0	0	0	1	19	26
Tillers - panicle (%)	0	0	0	0	0	0	5
Wild oat growth stage for flamprop-methyl pots[1]							
Tillers/plant	11.5	13.6	14.5	17.1	19.0	15.7	18.7
Tillers - vegetative (%)	100	100	99	79	57	19	29
Tillers - elongating (%)	0	0	1	21	42	64	42
Tillers - booting (%)	0	0	0	0	1	17	26
Tillers - panicle (%)	0	0	0	0	0	0	3

[1] Assessed using Zadok's scale. Vegetative = 10 to 29; elongating = 30 to 39; booting = 40 to 49; panicle = 50 to 59.

RESULTS AND DISCUSSION

Seed production was controlled by at least 89% for the first four times of application (late tillering to late stem elongation). After early booting, control of seedset declined but did not fall below 63%. Flamprop-methyl was consistently better than fenoxaprop-ethyl over the last five application times (Tables 2 and 3).

The wild oats in this experiment were not subject to competition from other species, moisture stress or other factors normally present in the field. Furthermore, although growth stages between the times of treatment were similar (Table 1) for pots assigned to each herbicide, maturity of plants was accelerated by glasshouse conditions and late planting. For instance, the period from the start of tiller elongation to panicle emergence was 17 days. Thus, levels of seedset control indicated by this experiment might not be achievable in the field situation where it is more difficult to minimise the effects of adverse environmental constraints. This is borne out by field experiments over two seasons and two sites which gave between 30% and 99% reduction in seed production using the same herbicides applied at similar growth stages and rates. In 1992, half the flamprop-methyl and 70% of the fenoxaprop-ethyl treatments produced greater than 75% seedset control. Also, flamprop-methyl appeared slightly less effective than fenoxaprop-ethyl under field tests and this could have been caused by the different growing conditions experienced in the glasshouse (Cook, unpublished data).

Table 2. Visual assessments and harvest data for wild oats sprayed at various times with fenoxaprop-ethyl.

Application time	1	2	3	4	5	6	7	Control
Panicle reduction (0-5)	4.9 a	3.9 b	3.8 bc	3.6 bcd	3.3 bcd	3.0 cd	2.8 d	0.0 e
Whole seeds/plant	1.2 a	53.0 a	35.0 a	40.0 a	133.0 b	189.0 b	173.0 b	517.0 c
Panicles/plant	0.2 a	2.7 ab	1.8 ab	3.4 ab	6.2 bc	7.6 bc	7.3 bc	11.3 c
Glumes/plant	1.0 a	47.0 ab	45.0 a	47.0 ab	98.0 bc	107.0 c	102.0 c	256.0 d
Whole seeds/glume	1.16bcd	1.05abc	0.64a	0.71ab	1.37cde	1.64de	1.77ef	2.20f
Whole seeds/panicle	1.2 s	17.6 bc	12.6 abc	7.9 ab	17.4 bc	23.4 c	20.5 c	45.7 d

Differences between means followed by the same letter are not significantly different (P=0.05) within parameters.

Table 3. Visual assessments and harvest data for wild oats sprayed at various times with flamprop-methyl.

Application time	1	2	3	4	5	6	7	Control
Panicle reduction (0-5)	5.0 a	4.0 bc	4.6 ab	4.4 a	3.3 cd	3.1 cd	2.8 d	0.0 e
Whole seeds/plant	0.4 a	55.0 ab	13.0 a	21.0 ab	91.0 b	78.0 ab	95.0 b	517.0 c
Panicles/plant	0.1 a	7.7 bc	3.8 ab	4.2 ab	12.8 c	10.6 c	8.5 bc	11.3 c
Glumes/plant	0.4 a	39.0 ad	13.0 a	14.0 a	69.0 b	71.0 b	85.0 b	256.0 c
Whole seeds/glume	1.56ab	1.45b	0.86a	1.36b	1.29ab	1.11ab	1.19ab	2.20c
Whole seeds/panicle	0.4 a	3.6 ab	1.4 ab	3.4 ab	6.5 ab	8.6 ab	12.1 d	45.7 c

Differences between means followed by the same letter are not significantly different (P=0.05) within parameters.

In the field, wild oat emergence is staggered and mixed seedling cohorts produce a range of growth stages, complicating the decision making process. Early application of post-emergence herbicides is generally recommended to minimise yield loss through competition, but this allows later germinating cohorts to survive and produce seed. This experiment confirms the potential for late application to control later germinating cohorts and also to significantly reduce seed production of fertile tillers not killed by earlier treatments. Consequently, where the objective is to minimise seed production, optimal timing is likely to be later in the field where mixed cohorts are present.

Both herbicides appear to warrant further investigation of the selective spray-topping concept which might also have advantages with regard to managing herbicide resistance. Field work aimed at optimising both rate and timing of herbicide application is in progress. Other aspects being examined include tank mixtures and additives, crop phytotoxicity and herbicide residues. A three year experiment is also examining the effects of pre- and post- emergence herbicide applications alone and in conjunction with selective spray-topping to quantify their effects on competition from wild oats and on soil seed bank populations.

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REPRODUCTION AND GENETIC VARIATION IN JOHNSONGRASS *(SORGHUM HALEPENSE)* POPULATIONS

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Summary. Johnsongrass is a perennial weed that is capable of reproducing by means of seed and rhizomes. Polymerase chain reaction-random amplified polymorphic DNA (PCR-RAPD) technique was used to examine the reproduction and genetic variation within 10 johnsongrass populations in Kansas. Two twenty-base primers provided a suitable number of fragments to distinguish between individual johnsongrass genotypes. All populations had different degrees of genetic variability, with the occurrence of many genotypes per population and few clones, indicating the importance of reproduction by seed in population maintenance and dissemination.

INTRODUCTION

Johnsongrass has been listed by Holm et al. (2) as one of the 10 worst weeds of the world. It reproduces by seeds as well as by rhizomes, and thus, is extremely difficult to control (4). To date, little is known of the frequency or importance of seed and rhizome reproductions to the maintenance and dissemination of johnsongrass. However, considerable intraspecific variation has been described for this weed species (1). The aim of this research was to examine the mode of reproduction and genetic variation occurring within johnsongrass populations.

METHODS

Sites and plant collections. Ten populations of johnsongrass were collected in 1991. The collection sites were located in the state of Kansas, USA on an east-west transect extending approximately 520 km and a north-south transect extending approximately 325 km. At each site, plants were selected at random and at intervals along a transect. Each plant was unearthed, all soil was removed from the roots, and the shoots were clipped back to 10 cm. The plants were transplanted to styrofoam cups containing a mixture of peat:sand:vermiculite (1:1:1, v/v/v). The plants were placed in a mist chamber for a week to allow for the re-establishment of roots and shoots, then removed from the chamber and transplanted to 15 cm plastic pots containing a mixture of peat:vermiculite:silt loam soil (1:1:1, v/v/v). Pots were arranged and maintained in a greenhouse by populations until DNA extraction.

DNA extraction. One gram leaf samples were obtained from the plants growing in the greenhouse. The samples were placed in a mortar, frozen with liquid nitrogen, and crushed with a pestle. Five mL of CTAB buffer was added during crushing. The mixtures were transferred to plastic test tubes and placed in a 65°C oven for 30 min. The tubes were removed from the oven, 5 mL of chloroform was added to each tube, then were centrifuged at 13,000 x g (2,200 rpm) for 15 min. The supernatants were transferred to new tubes, and 5 mL of isopropanol added to each to precipitate the DNA. The tubes were then placed in a -20°C freezer for 8 h. The samples were centrifuged at 13,000 x g for 15 min, and all solutions removed, leaving the DNA attached to the bottom of each tube. Two mL of TE buffer (3) were added to the DNA to resuspend it. The above procedures were repeated once to further purify the DNA samples.

Amplification. One µL (approximately 100 ng) of the DNA extract was added to a well on a PCR-assay plate containing 200 µL/L each of dNTP's, 12 pg/30 µL of either HPH-1 or HPH-2 primer, 20X reaction buffer and 0.3 units/30 μL reaction of the thermostable DNA polymerase (Replitherm™). Fifty cycles of PCR amplification were performed in a thermocycler (MJ Research™) with the following temperature profile: 94°C (2 min), 92°C (30 sec), 28°C (30 sec), and 72°C (1 min) followed by a final incubation period of 5 min at 22°C.

Electrophoresis and analysis. Amplification products were analyzed by electrophoresis in a 1.25% gels in half-strength TBE buffer and detected by staining with 0.5 ug/mL of ethidium bromide. A 1 kb ladder (BRL™) DNA marker was run on each gel. Gels were placed on top of a UV light source to reveal DNA bands and photographed. Gels were scored by recording the presence or absence of bands. Data were analyzed using PAUP (Phylogenetic Analysis Using Parsimony) computer software.

RESULTS AND DISCUSSION

The PCR amplification of the DNA using two twenty-base primers (HPH-1 and HPH-2) resulted in the amplification of discrete fragment profiles among the johnsongrass individuals that were examined. Results of our study indicated that Marshall and Scott Co. populations were the most diverse having 25 and 23 genotypes (out of 30 individuals), respectively. Overall data also indicated that clonal reproduction was predominant in 8 populations, while reproduction from seeds was higher in the remaining 2 populations. Genetic diversity within populations varied by location.

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GROWTH, BIOMASS ALLOCATION AND RESPONSE TO GLYPHOSATE OF *IMPERATA CYLINDRICA* GROWN UNDER DIFFERENT LIGHT CONDITIONS

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Summary. Lalang (*Imperata cylindrica*) was grown from seed in a greenhouse 0, 50 and 75% shade to determine the vegetative response, partitioning of biomass allocation and response to glyphosate treatment. Leaf area of *I. cylindrica* increased as shade level increased. Dry matter of shoots, roots and rhizomes declined as shade level increased. Shading significantly influenced the pattern of biomass allocation of *I. cylindrica* as was clearly shown by the different values of leaf to root weight ratio, leaf area, net assimilation rate and leaf area duration. Placement of plants originally from three shade levels to 0% shade or vice versa resulted in different patterns of biomass allocation and response to glyphosate treatment. The activity of glyphosate was significantly enhanced with increase in light intensity.

INTRODUCTION

Imperata cylindrica Raeuchel is an important perennial weed in Malaysia and many other countries in Southeast Asia. It is one of the ten worst weeds in the world and regularly infests many crops (5). It is aggressive and has an extensive rhizomatous system (11) and reproduces proficallly from both seeds and rhizomes (6). For many years control of this weed has been attempted using mechanical, cultural, chemical and combined methods, but little attention has been paid to the role of environment and its effects on plant growth rate, vigour and competitive ability. These studies were designed to determine growth, biomass allocation and response to glyphosate of *I. cylindrica* grown under different light conditions.

MATERIALS AND METHODS

Three shade levels (100% available sunlight, 50 and 75% shade) were used in this study. At 35 and 42 days after planting, four plants from each shade level were harvested. Leaf areas, height of the longest extended leaf and total plant dry weights (65°C oven-dried) were determined. At the 42-day harvest, the dry weights of leaves, stems and roots were also determined for growth analysis by a standard method (10).

The activity of glyphosate on *I. cylindrica* was determined by applying 1.0, 1.5 and 2.16 kg a.i/ha of glyphosate at 400 L/ha with knapsack sprayer. All experiments were arranged in a randomised complete block design with 5 replicates.

RESULTS AND DISCUSSION

Decreasing the light intensity tended to increase the plant height (Table 1). Plants at 0% shade produced significantly more leaves and tillers than those from 50 and 75% shade. Reduction of light intensity to a certain degree had resulted in increase stem elongation and leaf size of *Solidago virgaurea* (1), but further reduction of light significantly reduced the vegetative growth of the plants. This pattern of growth was also observed on *I. cylindrica* (9, 12).

Partitioning of plant biomass into leaves and rhizomes differed significantly among the plants from the three shade levels. At 75% shade, the plants partitioned more biomass into leaves and less into rhizomes than the other two light regimes (Table 2). However, the shoot to root weight ratios did not differ significantly between shade levels. Leaf area and leaf area ratio significantly increased with increase in shade. Both specific leaf area and leaf area ratio were greatest at 75% shade. Leaves produced under shade conditions were generally thinner then those produced in unshaded treatment (2). This concomitant increase in specific leaf area and leaf weight ratio indicated that the amount of leaf area per unit of plant weight was increased by shading. The dry matter production (DMP), net assimilation rate (NAR) and leaf area duration (LAD) at 50% shade were significantly higher than those from 0% and 75% shade (Table 3), and were lowest at 75% shade.

Table 1. The height, leaf and tiller number of *I. cylindrica* grown under different shade levels at tenth week of transplanting.

Shade level (%)	Height (cm)	No. of leaf	No. of tiller
0	64.8b	65.0a	29.3a
50	72.5a	37.5b	13.8b
75	71.8a	27.5c	9.5c

Within each column, values sharing the same letter are not significantly different at 5% level, according to Duncan's multiple range test.

Table 2. Effect of shading on vegetative growth, leaf area production and biomass allocation in *I. cylindrica*

Shade level (%)	LWR	SWR	RhWR	SLA	LAR
	(g/g)			(cm^2/g)	
0	0.398b	0.258a	0.117a	178.1b	70.9c
50	0.377b	0.265a	0.228a	288.4a	108.7b
75	0.514a	0.289a	0.129a	298.6a	153.4a

Within each column, values sharing the same letter are not significantly different at 5% level, accordin to Duncan's multiple range test.

Table 3. Effect of shading on dry-matter production (DMP), net assimilation rate (NAR) and leaf area duration (LAD) of *I. cylindrica* during the 35th to 42nd-day interval after transplanting

Shade level (%)	Height (cm)	No. of leaf	No. of tiller
0	3.8b	0.00111a	9619.9b
50	19.0a	0.00293a	12970.2a
75	2.9b	0.00051b	2448.6c

Within each column, values sharing the same letter are not significantly different at 5% level, according to Duncan's multiple range test.

Control of *I. cylindrica* by glyphosate was significantly improved with increasing light intensity (Fig. 1). Plants under 0% shade were completely killed at 1.5 and 2.16 kg a.i/ha 21 days after treatment, compared with only about 50% at 2.16 kg a.i/ha under 50 and 75% shade, 21 and 28 days after treatment respectively. Different growth patterns and physiological characteristics of plants can influence herbicide performance by affecting spray interception, retention, uptake and translocation of herbicide (7). Placement of the treated plants at 75% shade severely decreased the phytotoxicity of glyphosate on *I. cylindrica* (Fig. 1). At 0% shade, 100% control was recorded with 1.5 kg a.i/ha, but it required 2.16 kg a.i/ha at 50% shade, 35 days after treatment. The rate of the control reduced to only 53% with 2.16 kg a.i/ha at 75% shade during the same interval. Light intensity enhanced the onset of activity of imazapyr against *I. cylindrica* (8). Increased activity under high light intensity was mainly due to the increase of herbicide percentage distribution in plants.

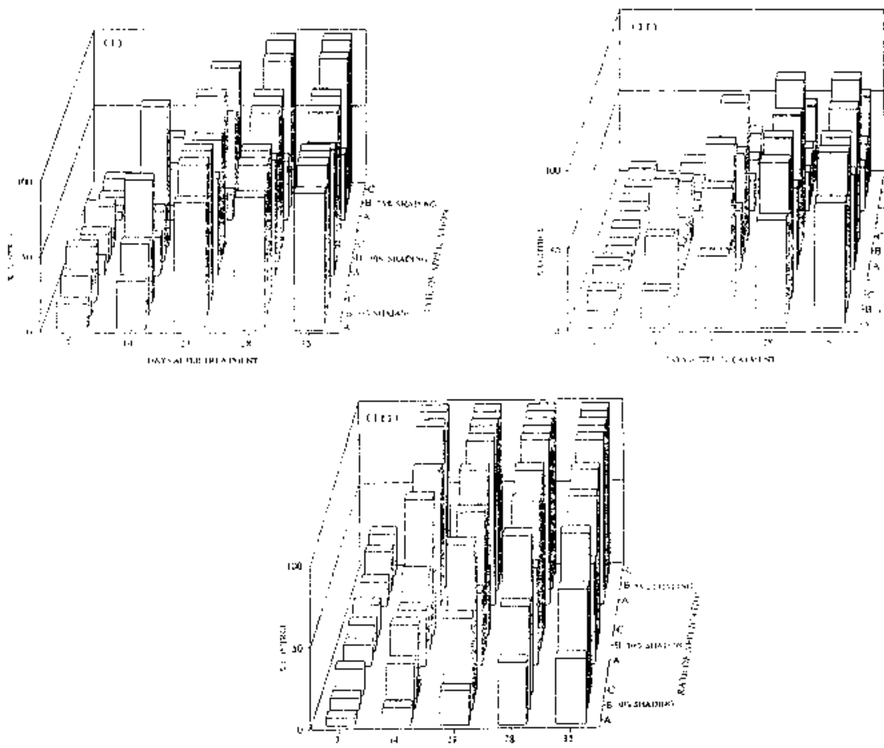

Figure 1. Effect of shading on control of *I. cylindrica* by glyphosate (I). Remained at three shade levels (II). Transferred from 0% shade to 3 shade levels (III). Transferred from three shade levels to 0% shade A = 1.0 kg a.i./ha; B = 1.5 kg a.i./ha; C = 2.16 kg a.i./ha.

Treated plants initially at 75% shade were completely killed even at the application rate of 1.0 kg a.i/ha, 21 days after treatment (Fig. 1). Complete control required 2.16 kg a.i/ha for plants initially grown under 50% shade. Plants grown at higher light intensities were slower to develop phytotoxic symptoms and damages was still minimal 35 days after treatment. Plants exposed to high light intensity experienced an increase in photosynthetic products which may have caused an increase in the translocation of herbicide immediately after spraying.

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REPRODUCTIVE STRATEGY OF *EQUISETUM ARVENSE* L.

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Summary. The rhizome of elongation of *Equisetum arvense* L. started soon after the growth of shoots, but the formation of tuber followed two months later than rhizome elongation. The greater part of dry matter production was partitioned into rhizome and tuber, and 75% of dry matter partitioning ratio to rhizomes and tubers was observed in the maturing growth stage. Rhizomes were more tolerant against drought or high temperature stress than tubers. The growth of rhizome originating from tuber was more rapid than that from rhizome.

INTRODUCTION

Equisetum arvense L. is one of the most common perennial weeds in Japan and is difficult to control. It is growing on eighty percent of agricultural area in Japan (2), and it has been enhanced by recent extension of minimum- or no-tillage conservation. Problems of this weed are more serious in cool agricultural zones, i.e. northern part of Japan, especially in pasture. Because *E. arvense* contains thiaminase enzyme, animals eating this weed become deficient of vitamin B_1 (1).

E. arvense propagates both by sexual reproduction (spores) and by asexual reproduction (rhizomes and tubers). Ecological features of their propagative organs are not characterised well. Some experiments were carried out to enable to design the reasonable control method of this weed.

METHODS

1. Germination and establishment of spores. The fertile cones of *E. arvense* were collected from fields in Tsukuba for the materials in the experiment. The spores produced in sporangium in a desiccator were put on MS medium or volcanic ash soil. The effects of some environmental conditions on the germination and establishment of spores were examined by various treatments as follows: (i) pH of MS medium: pH 3.7, 4.5, 5.7, 6.8, 7.4; (ii) Temperature: 5, 15, 20, 25, 30°C; (iii) Soil moisture: pF 1.0, 1.5, 2.0, 2.7, 4.0; and (iv) Gas condition: 100% N_2 gas, air with sealed or ventilated condition.

2. Reproduction of rhizomes and tubers. Three tubers were planted into 1/5000 a Wagner pot filled with volcanic ash soil on 7 June 1988 without any fertiliser, and were placed outside. Dry weight of each organ was measured monthly. Five tubers or two rhizomes with three nodes were also planted into 1/5000 a Wagner pot filled with volcanic ash soil. These were set up in a water bath controlled at 15, 20, 25 and 30°C. The amount of reproduction of newly formed tubers or rhizomes were examined six months after planting.

3. Tolerance of rhizome and tuber against environmental stress. Responses to some kinds of stress were compared between rhizome and tuber. Tubers and rhizomes cut into segments with three nodes were subjected to experiments as follows:

(i) Low temperature: The segments were put into soil with 66% soil moisture condition, and incubated at -1, -3 and -5°C for 1, 2, 4 and 7 days.
(ii) High temperature: The segments set in grass tubes were put into the water bath controlled at 40, 45, 50, 55 and 60°C for 5, 10, 20, 30, 60 and 120 minutes.
(iii) Drought condition: The segments set in petri dish were put into drying incubator controlled at 25°C for 20, 45, 60, 90 and 180 minutes.

RESULTS AND DISCUSSION

1. Germination and establishment of spores. Responses of spore germination to some environmental factors were summarised as follows:

(i) pH: Range for normal germination: pH 4.5-6.5, Optimum: pH 5.7.
(ii) Temperature: Range for normal germination: 15-30°C, Optimum: 20°C.
(iii) Soil moisture: Spores could germinate at the soil moisture condition less than pF 2.7, but prothallium was produced less than pF 2.0 (Table 1).
(iv) Gas condition: Spores could germinate without O_2.

Table 1. Effect of soil moisture on germination of spores, development after germination and formation of prothallium

pF	Germination	Development	Prothallium
1.0	good	good	formed
1.5	good	good	formed
2.0	good	good	formed
2.7	medium	bad	no
4.0	bad	dead	no

It is known that the numerous spores are produced (1), but the results obtained here suggest that it is very difficult to establish the plants of *E. arvense* from spores under natural conditions.

2. Reproduction of rhizomes and tubers. The elongation of rhizomes started soon after the onset of shoot growth. The total length of new rhizomes reached about 50 cm/plant 4 months after planting. The formation of tubers followed two months later than rhizome elongation. Finally six tubers/plant were newly formed.

Fig. 1 shows changes in dry matter partitioning ratio to each organ during growing period. When the shoots started growth, the dry matter partitioning ratio to shoot was higher than 75%. During August dry matter partitioned into underground organs was increased. In September the dry matter partitioning ratio to rhizome and tuber reached 75%.

Temperatures affected the tuber formation from rhizome or tuber responded similarly. In both cases, optimum temperature for tuber formation was observed at 20°C, and tuber formation was decreased at 30°C.

On the other hand, temperatures affected rhizome elongation from tuber or rhizome differently. Total length of new rhizomes from tuber was longer than those from rhizome, except at high temperature (Fig. 2).

The partition of photosynthetic products to rhizomes and tubers starts from early growth stage and at maturing growth stage the greater part of photosynthates translocates to their under ground propagative organs.

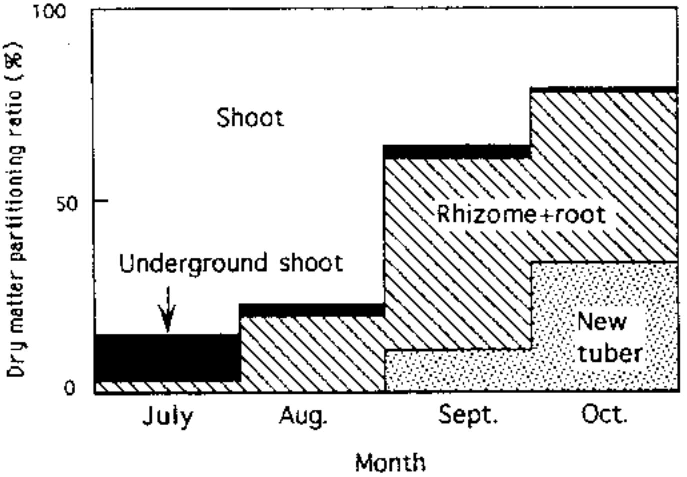

Figure 1. Changes in dry matter partitioning ratio into each organ during growth season.

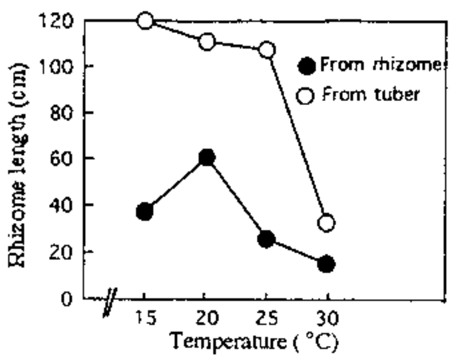

Figure 2. Difference in response of rhizome elongation to temperature between rhizome from rhizomes and that from tubers.

3. Tolerance of rhizome and tuber against environmental stress. The ratio of emergence of tubers and rhizomes was decreased by the treatment of -3 or -5°C for a day. Treatments of -3 or

-5°C longer than 2 days killed all buds on tubers and rhizomes. Treatment of -1°C did not influence the emergence even for 7 days.

Buds of tubers were killed by treatment at 45°C for 60 minutes, or 50°C for 10 minutes. Those of rhizomes were not killed by treatment at 45°C for 120 minutes but killed by treatment at 50°C for 30 minutes.

The emergence of buds of rhizome was decreased when moisture loss of rhizome reached 40%, and all buds of rhizomes were killed when the moisture loss reached 62%. Emergence of buds of tubers was decreased when the moisture loss of tubers reached 10%, and all buds of tubers were killed when the moisture loss reached 25% (Fig. 3).

These results indicate that the emergence ability of rhizomes is more tolerant against high temperature and drought stress than that of tubers.

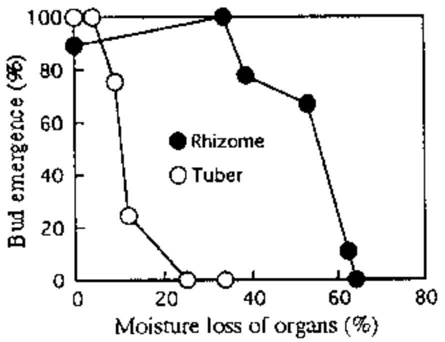

Figure 3. Difference in tolerance of germinating ability to water stress between rhizomes and tubers.

<u>Conclusion</u>. Rhizomes are more tolerant against severe environmental condition than tubers. On the other hand, the growth of rhizomes originated from tuners is more rapid than those from rhizomes. The vigorous reproductive ability of *E. arvense* depends on different characteristics of tubers and rhizomes in the propagative strategy.

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THE EFFECT OF GERMINATION STIMULANTS ON SEEDLING EMERGENCE OF WILD OAT (*AVENA FATUA*) FROM SOIL

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Summary. The effect of potassium nitrate (200 mM) and ethephon (1 mM - an ethylene releasing chemical) on promoting emergence from buried seed was variable with both treatments similar to one another and no synergism noted when used together. Examination of exhumed seeds showed that these treatments had a secondary effect, reducing seed viability. By counting the number of dead and adding to the proportion stimulated to emerge, a value for removing seeds from the soil was obtained. Under this type of analysis it was clear that all treatments had the ability to remove seed from the soil seed bank especially when the seed was old, near the soil surface, were primary (large) seed or from low or intermediate dormancy isogenic lines. However, based on overall considerations, it is unlikely that either potassium nitrate or ethephon could be recommended for future field application to remove a significant proportion of the wild oat seeds from the seed bank.

INTRODUCTION

Wild oat (*Avena fatua* L.) is a persistent annual weed in most winter cereals throughout the world. It owes its success to seed dormancy and to long term viability of seeds in the soil (6). Consequently seedlings emerge irregularly over a period of several weeks to many years. Repeated application of conventional herbicides can be used to control seedlings, however, such treatments have little or no effect on the dormant seeds in the soil seed bank. Application of germination stimulants to force early, synchronous germination and eliminating the seedlings with herbicides has been suggested as a way to eradicate the dormant, persistent portion of the weed seed bank (5). Several chemicals are known to overcome wild oat dormancy under laboratory conditions. Of these ethylene and nitrate are perhaps the best suited for field simulations. Ethylene can be conveniently applied as ethephon, a water soluble compound that releases ethylene into the soil and plant materials. The response of wild oat seed to nitrate and ethylene will depend on seed age (1, 3), with young seeds less responsive than older seeds. The response will also depend on whether the seed is primary or secondary seed from the spikelet (1).

The objects of this study are to: Determine the effects of potassium nitrate and ethephon on wild oat germination and emergence in a pot trial, determine the difference, if any, between isogenic lines, and determine if factors such as age, depth of planting, and whether the seeds are primary or secondary will influence the loss of seed from the seed bank.

MATERIALS AND METHODS

<u>Seed material</u>. Seed collected from three growth cabinet grown isogenic lines were used (3). These lines represent dormancy types from low dormant (CS166), intermediately dormant (AN51), to deeply dormant (M73). Seeds were used at harvest (young seeds) or after-ripened (4) for six months (old seeds). At the time of harvest a distinction was made between primary (largest seed, basal position in the spikelet) and secondary (smallest seed, top position in the spikelet) seed. The viability of all seed lots used was *ca.* 100%.

Burial of seed. The soil used in this study was a composite sandy loam clay having a pH of 7.0 and 5% organic matter. Weighed amounts (4.5 kg) of the soil were placed into plastic bags; and distilled water or treatment solution added to obtain negative 0.03 MPa (field capacity). The sealed bags were shaken occasionally to ensure uniform solution distribution. The moist soil was then transferred to 20 cm diameter plastic pots (2 L) and planted with 20 seeds at a depth of 2 or 5 cm. Lost water was replaced daily. The pots were placed in a glasshouse maintained at approximately 25°C day, 18°C night and a natural photoperiod of 13 hours day. Coleoptile protrusion was the emergence criterion and counts were made daily until emergence was complete. All remaining seeds were washed free of soil, counted and transferred onto filter paper in 9 cm Petri dishes. Seeds were microscopically examined to determine both intact, non-germinated seeds, and empty seeds that had germinated or lost viability.

Treatments. In a preliminary experiment, potassium nitrate (KNO_3) and ethephon were applied to bring the air dried soil to field capacity to produce final soil concentrations of 0, 100, 200, 350 or 500 mM KNO_3 and 0, 0.1, 1.0, 10 or 50 mM ethephon. Each treatment was replicated 3 times and applied to primary, hulled seed of lines CS166 and AN51 (both after-ripened for 3 months) planted at a depth of 2 cm. The results of this experiment were used to select one concentration each of KNO_3 and ethephon to be used in subsequent trials. The first trial investigated the effect of KNO_3 and ethephon, alone and in combination, on primary, hulled, young and old seeds of CS166, AN51 and M73, planted at either 2 cm or 5 cm below the soil surface. The second trial consisted of exactly the same treatments but the seed used was secondary seed.

Statistical Analyses. Emergence and dead seed counts were added together, normalized by an arc-sine transformation ($[X/100]^{½}$) and subjected to a factorial analysis of variance.

RESULTS AND DISCUSSION

Pretrial. Increasing KNO_3 rate from 100 to 200 mM increased seedling emergence (Fig. 1). However, as rate was increased to 500 mM effect on emergence was less pronounced due to a reduction in viability. Ethephon, an ethylene-releasing compound, could also stimulate seedling emergence however in a much narrower band of concentrations than that seen with KNO_3. Increasing ethephon rate from 0.1 to 1 mM increased seedling emergence, however above this rate the chemical progressively reduced viability. At the best concentrations both chemicals could stimulate the emergence of primary, hulled seed of line CS166 planted at a depth of 2 cm by as much as 40% above the control. These two concentrations, 1 mM ethephon and 200 mM KNO_3, were used in all future trials. A similar, but much smaller promotion of emergence (25 and 15% for KNO_3 and ethephon respectively), were observed for AN51 at the peak concentrations.

Effect of chemicals. The effect of KNO_3 and ethephon on promoting emergence from buried seed populations from three biotypes and treated under several conditions was variable with both treatments similar to one another and no synergism noted when the two were used together (data not shown). Examination of exhumed seeds showed that these treatments had had a profound effect on the viability particularly of the larger seeds (primary seed). Unsound seeds were discovered which had either germinated and failed to reach the soil surface or had lost the integrity of their endosperm tissue. By counting the number of dead seeds/seedlings and adding to the proportion stimulated to emerge by the same treatment provided a method for looking at the total effectiveness of these chemical treatments in removing seed from the seed bank. Under this type of analysis it was clear that all treatments had the ability to remove seed from the soil seed bank whether by emergence or by killing the seed. This was dependent on the isogenic line planted, seed age, seed size and depth of planting (Fig. 2).

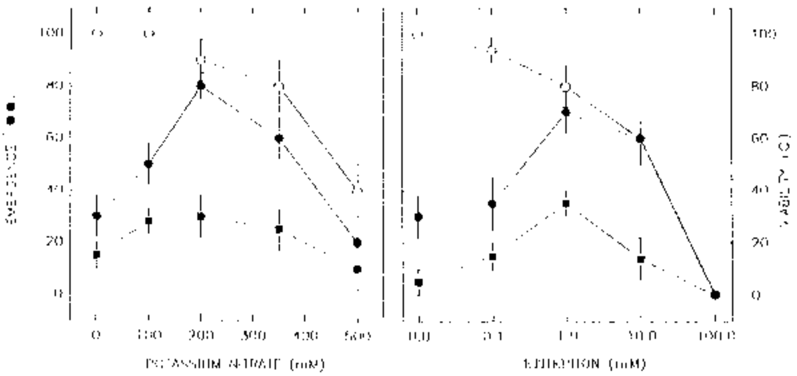

Figure 1. Percentage seedling emergence from primary seeds of wild oat lines CS166 (•) and AN51 (■) following treatment with potassium nitrate and ethephon. The seeds were after-ripened for 3 months and were planted at a depth of 2 cm. The ungerminated seeds of CS166 were recovered and the total viability determined (○). Error bar = ± SE.

<u>Biotypes</u>. Combined killing of the seeds and emergence was greatest in the least dormant (CS166) line (Fig. 2). With the most dormant line (M73) some seeds were killed, especially those planted at depth but little effect on dormancy was observed. The difference between lines in their response to KNO_3 and ethephon observed here is thought to be related to the existence of a persistent block to germination that exists in all lines but is most intense and persistent during after-ripening in the order M73 > AN51 > CS166 (4).

<u>Age</u>. The effect of KNO_3 and ethephon on promoting seed loss from soil when partly after-ripened seeds were planted was much greater than that seen when freshly harvested seeds were planted (Fig. 2). This was especially true for primary, hulled seeds of the least dormant lines (CS166 > AN51). The difference between seedlots of different ages in their response to KNO_3 and ethephon observed here is thought to be related, as explained above, to the existence of a persistent germination block that exists in freshly harvested seeds of all lines but has been overcome (CS166), partly overcome (AN51) or still present (M73) in partly after-ripened seeds.

<u>Seed size</u>. There is evidence that secondary seeds are less affected by the treatments than primary seeds, especially when planted at depth (Fig. 2). It has been shown before that secondary seeds have a deeper dormancy than primary seeds (1). In addition it may be expected that a small seed will intercept less KNO_3 and ethephon in the soil than larger primary seeds.

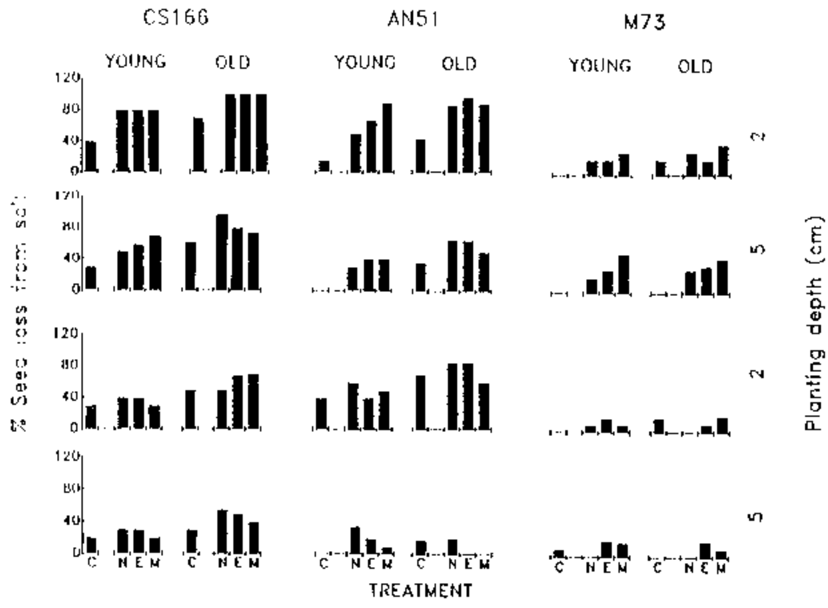

Figure 2. The combined percentages of seedling emergence and seeds killed from primary seeds (Fig. 2A), or secondary seeds (Fig. 2B) of wild oat lines AN51, CS166 and M73 following treatment with distilled water (C), potassium nitrate (100 mM; N), ethephon (1 mM; E) and a mixture of the two substances (M). The seeds were planted at either 2 or 5 cm and were either freshly harvested (young) or partly after-ripened at room temperature for six months (old).

Depth of planting. There is evidence that seed at 2 cm depth are more affected by the chemical treatments than at 5 cm depth. It may be expected that the conditions for germination and emergence are more suitable at the 2 cm depth than the 5 cm depth and this is the reason for better emergence at 2 cm than 5 cm. A further observation is that at the shallower depth seeds are promoted to emerge while at depth viability is upset more.

Conclusions. It is difficult to predict from these data what may happen in the field. It could be speculated that where there is a predominance of low dormancy families (like CS166), as is the case with a continuous cropping situation (6), then application of KNO_3 or ethephon may be of some use cleansing the seed bank. However, in a second situation where there is a predominance of dormant families (like M73), as is the case with a summer fallow situation (6), then application of these chemicals will do little towards reducing the seed bank. Even in the first situation the suggestion is that within the population of seeds a large proportion would fall into the category of being insensitive to promotion, in other words, are freshly shed seeds, are secondary seeds, or are at depth. In a typical situation in the field a large proportion of the seed would fall within one of these difficult-to-stimulate categories. Thus, based on overall considerations, it is unlikely that either KNO_3 or ethepon, alone or in combination, could be recommended for future field application to remove wild oat seeds from the seed bank.

ACKNOWLEDGEMENTS

The author expresses gratitude to several students who, as part of their degrees, carried out confirmation experiments to those reported in this manuscript.

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EFFECT OF TIME OF EMERGENCE ON REPRODUCTIVE BIOLOGY OF AUSTRALIAN POPULATIONS OF WILD OAT (*AVENA FATUA*)

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Summary. Wild oat (*A. fatua*) plants emerging earlier in the season had a longer life span though all plants set seed in a short period during October and November. Plants emerging earlier also were larger in stature producing more tillers, shoot dry matter and seeds which had low levels of dormancy. Plant growth and reproductive output of some lines was correlated closely with the photoperiod regime during plant growth. Some polymorphism was shown between the lines used in this study in both plant biology characteristics and their overall response to different emergence dates.

INTRODUCTION

The main persistence mechanism for wild oats (*Avena fatua*) is its ability to produce copious numbers of dormant seeds which germinate irregularly from the soil seed bank over the course of the season (5). Earlier growth cabinet studies have determined that *A. fatua* when exposed to varying environmental conditions such as photoperiod, temperature and water stress show marked differences in phenology, plant morphology and seed characters. For example *A. fatua* are long day (LD) plants with LDs hastening flowering and resulting seeds with low levels of dormancy (6). Most earlier studies have looked at these environmental effects under constant conditions in controlled growth cabinets. These studies are not always appropriate for analysing developments in the natural environment as they not take into account that the photoperiod is constantly changing and that plants react differently in pots than in swards. To overcome these concerns studies have been carried out to assess the effect of varying photoperiods by planting at different sowing dates (7) but these previous studies have not taken into account the genetic variability that is known to exist within the population (3,1). It is therefore more appropriate to study these effects using isogenic lines rather that heterozygous field populations.

The aim of this study is to determine if changing environmental regimes, as a result of different times of emergence in the field, has any effect on the seed production, dormancy and viability of *A. fatua*. To help understand any changes that may occur in these characters other morphological characters (*viz.* phenology, tiller and shoot biomass production) were recorded. Near isogenic lines chosen for study were from a small geographic location and this was expected to show the extent of polymorphism that may exist for environmental response within the study area.

METHODS

The field trial was carried out at Hermitage Research Station, near Warwick Queensland between April and December 1991. Six near isogenic lines from southern QLD and northern NSW were sown at 5 different times over the course of the season. The experimental design was a split plot design replicated in blocks comprising the 5 emergence dates as main plots, and isogenic lines as subplots. Each planting (2x14 m) comprised 6x1 m^2 subplots. Seed was pregerminated and hand planted in each plot at a density of 40 seeds/m^2 and grown to seed maturity. Measurements were made on phenology (time to floral initiation, anthesis and seed maturation), on plant morphology; fertile and total tiller and shoot production, and on reproductive biology;

an estimate of primary seed production (by measuring flower production due to the difficulty in collecting all dehisced seed), weight, dormancy and viability. Primary seed dormancy was assessed by imbibing caryopses in water and several concentrations of gibberellic acid (GA_3), a germination stimulant, for 20 days dark incubation at 20°C. A Pearson' Correlation Analysis was made comparing plant biology characteristics with cumulated photoperiod, a summation of the daily photoperiod (h) experienced during plant growth.

RESULTS AND DISCUSSION

Only results from two of the isogenic lines used in this study will be discussed in the scope of this paper. Trends shown by these lines are representative of all lines used in the initial study.

Plant Characters. Plants emerging early in the season were exposed to shortening days of autumn compared to those emerging later in the warming and lengthening days of spring. Early emerging plants had a longer life span but all plants regardless of emergence date flowered and set seed in a short period from mid October to mid November (Fig 1a). This would indicate a LD response with flowering hastened by lengthening days and supports earlier growth cabinet studies (6) and field studies (7). There was little polymorphism in duration of life span but some variation in response to different emergence dates amongst the lines studied. Plants emerging earlier is the season, and exposed to shorter days were found to produce more tillers (Fig 1b) which supports earlier field studies (7) but is in contrast to earlier growth cabinet studies (2). These plants also produced greater shoot production compared to later emerging plants (Fig 1c) with some polymorphism between the different lines studied.

Seed Characters. Those plants emerging earlier possessed a greater flower and seed production (Fig 1d) as these plants grew best under those conditions, producing the greatest tiller and shoot production. These results supports earlier studies (7). There was also some degree of polymorphism in the seed production between lines studied. Interestingly, little difference was found in the seed weight produced by plants emerging at different times (Fig 1e). This observation is in contrast to earlier growth cabinet studies, which showed that under conditions which result in a long life span small seeds are produced (1). Variations in seed size may be important in the persistence of *A. fatua* as seed size has previously been linked to longevity with small seeds less prone to predation and fungal attack in the soil seed bank (5) but this may not be the case in this instance. Differences were also found in the level of seed dormancy amongst the lines used in this study. Seeds produced by plants emerging in July were more dormant than other seeds (Table 1), though showed no difference in viability. Previous studies have suggested that plants with a short life span produce less dormant seeds (1) but this was not the case in this study.

Implications. The ultimate success *A. fatua* is due to its ability to produce large numbers of dormant viable seeds. This process is dependent on conditions experienced by the parent plant which has a bearing on initial plant growth and reproductive output. Some lines showed a correlation between plant biology and photoperiod exposure (Table 2). Plants emerging earlier with a longer cumulative photoperiod were larger in stature, produced more tillers and shoot dry matter and more seed with a low degree of seed dormancy. This may indicate how varying photoperiod regimes can determine the persistence of *A. fatua*. Irregular emergence of seeds from the soil seed from the bank results in plants being produced which are of different age and morphology and have been exposed to varying photoperiod regimes. These plants produce seed over a short peri/d and show phenotypic polymorphism in both numbers produced and dormancy characters. Regardless of emergence date, some seed is produced that is capable of emerging irregularly from the seed bank. There was both some polymorphism in plant biology characters and the overall response to different emergence dates in the lines studied.

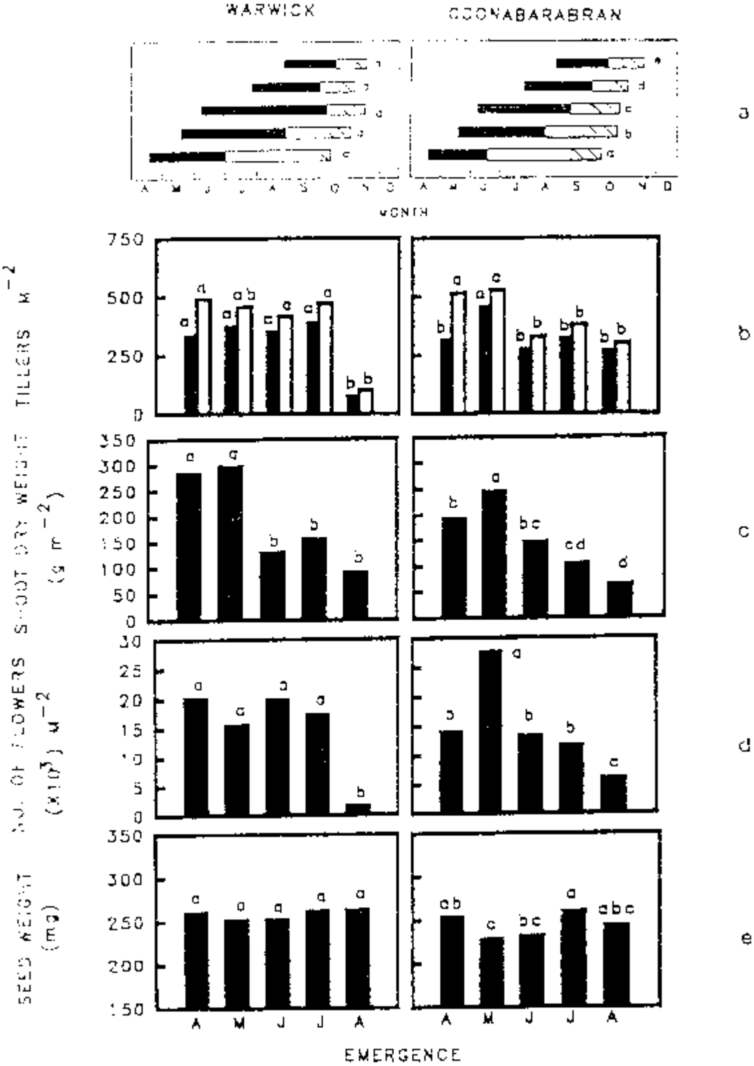

Figure 1. The influence of different emergence dates on the (a) phenology ; vegetative phase (■), reproductive phase (□), and maturation phase (□) (b) fertile (■) and total tiller (□) production (c) shoot dry weight, (d) seed production (flower production) and (e) seed weight of 2 near isogenic lines of *Avena fatua*. Values with the same letter are not significantly different (5% level) in each line.

Table 1. The influence of different emergence dates on the depth of seed dormancy (Germination % in 500 µM GA_3) of 2 near isogenic lines of *Avena fatua*. Values with the same letter are not significantly different (5% level) for each line.

Line	Emergence date				
	April	May	June	July	August
Warwick	95 a	68 ab	93 ab	30 b	73 ab
Coonabarabran	98 ab	98 ab	100 a	35 c	85 a

Table 2. Correlation of plant biology characteristics of 2 near isogenic lines of *Avena fatua* with cumulated photoperiod experienced during plant growth, using Pearson's Correlation Analysis. Coefficients are statistically significant at 5% (*), and 1% (**).

Characters	Pearson's correlations (vs. cumulated photoperiod)	
	Warwick	Coonabarabran
Total life span	0.97**	0.99**
Fertile tillers	0.01	0.28
Total tillers	0.56**	0.60*
Shoot production	0.78**	0.65**
Seed production	0.72**	0.51
Seed weight	0.43	-0.14
Seed dormancy	0.25	0.80*

ACKNOWLEDGMENTS

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REGENERATIVE CAPACITY OF ROOT FRAGMENTS OF *CARDARIA DRABA*

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Summary. *Cardaria draba* roots collected from a field infestation in autumn 1990 were separated into three thickness classes, cut into 5 or 10 cm pieces and planted in pots at 2, 5 or 10 cm depth. Shoot emergence was recorded. Shoots emerged from all fragment classes and lengths at all depths. The overall mean number of emerged shoots per viable root fragment was 2.0. The mean percentage of fragments which produced shoots was 41% but it varied widely between treatments. Calculations based on these data indicate that a *C. draba* shoot density of over 5,000 per square metre could result from regrowth from root fragments within 4 weeks of cultivation.

INTRODUCTION

Cardaria draba, hoary cress, is a significant weed of crops in many temperate areas of the world (2). Its declaration under Noxious Weeds legislation in five Australian States (4) is indicative of its serious weed status in this country.

C. draba is an herbaceous perennial plant, regenerating each autumn from an extensive root system which may reach a depth of 9 m (1). Following cultivation of infested areas, the plant is capable of regrowth from roots below the depth of cultivation (5) and from root fragments (6). The plant may also spread to new areas following transport of root fragments on cultivation implements.

This paper reports work which studied the regenerative capacity of root fragments as part of a wider research program to develop integrated control methods for *C. draba* in intensive cropping systems.

METHODS

C. draba roots were collected from a heavily infested pasture at Kempton in the Midlands area of Tasmania on 19 March 1990, about the time when seed-bed preparation would begin for an autumn-sown field crop in the region. The area had not been cultivated for at least 5 years. At the time of sampling, *C. draba* had completed its seasonal growth cycle and no green shoots were present.

All *C. draba* roots large enough to be readily separated from the associated grass roots were collected from an area 1 m x 1 m x 10 cm deep. Roots were washed carefully and then separated (with cutting as necessary) into three "thickness" classes based on lignification and size (Table 1). Within these classes, roots were cut into 5 and 10 cm lengths.

On 21 March 1990, the root fragments were planted at depths of 2, 5 or 10 cm in 20 cm diameter plastic pots filled with a 50/50 composted pine bark/sand medium. Seven fragments of one of the six thickness x length categories were planted in each pot with five replicates of each depth treatment. Pots were maintained in a semi-controlled glasshouse environment (temperature range 10 to 25°C) with daily watering.

The time of emergence of shoots at the soil surface was recorded. At four, ten, sixteen and twentysix weeks after the start of the experiment, pots with shoots at the surface were emptied. *C. draba* root fragments with emerged shoots were recorded and discarded. The remaining fragments were replanted as before, using the same soil and taking extreme care not to damage any shoots present which had not yet reached the soil surface. At twenty-six weeks, emergence had almost finished and thereafter fragments were removed from pots as shoots emerged. The trial was terminated 52 weeks after the initial planting.

Data were analysed by analysis of variance for a completely random design of three thickness x two length x two depth factors at each of two times. Mean shoot number per fragment and percentage of fragments which produced emerging shoots were the parameters analysed. The latter data were transformed (arcsin $\sqrt{X}$) prior to analysis.

RESULTS AND DISCUSSION

The total fresh weight of roots collected from the sampled area was 372 g.

The first shoots emerged 10 days and the last shoot 51 weeks after planting. Over 99% of the final shoot number had emerged by 26 weeks and this was taken as the finish of the trial for data analysis.

The rate of shoot emergence was high over the first four weeks and decreased thereafter. Over all treatments, shoot emergence during this initial four week period was 68%, 80% and 89% of the final shoot number for thickness classes 1, 2 and 3 respectively.

For the fragments which produced emerged shoots, the overall mean shoot number per fragment was 2.0, with a maximum of five.

Mean shoot number per fragment (SN/F) was significantly greater for thickness class 2 (1.23) than for the other two classes (0.58, 0.69) and almost twice as high for the 10 cm fragment length (1.10) than for the 5 cm length (0.56). Final SN/F at 10 cm depth of planting (0.52) was significantly less than for the other two depths (1.04, 0.93).

Over all treatments, the greatest SN/F at all times of sampling was for thickness class 2 fragments of 10 cm length planted at 2 or 5 cm (Table 1). Thickness class 1 fragments of 5 cm length generally had the lowest emerged shoot number. The relative differences between treatments were the same at the 4 and 26 weeks sampling times (Table 1).

Overall, 41% of the 630 fragments produced at least one emerged shoot over the 52 week duration of trial.

The percentage of fragments with emerged shoots (%FS) was significantly greater for thickness class 2 (65%) than for the other two classes (35%, 22%) and for the 10 cm fragment length (51%) relative to the 5 cm length (30%). Overall, depth of planting had no significant effect on %FS.

The %FS was greatest for 10 cm fragments of thickness class 2 and least for 5 cm fragments of class 1 and both lengths of class 3 fragments (Table 1). As for SN/F, the relative differences between treatments were the same at the 4 and 26 weeks sampling times (Table 1).

A similar trial has been conducted in England (6) in which *C. draba* roots were collected from the field in April (northern hemisphere spring). Although the root fragments used were smaller at between 1.3 and 5.0 cm in length, the overall viability of fragments was greater (approx. 75%) than in the current trial. The mean number of shoots per fragment was similar. The rate of emergence was considerably less in this earlier trial, even though the maximum depth of planting was less (7.5 cm). These results indicate that *C. draba* is able to regenerate readily from root fragments in both spring and autumn.

Limited observation indicates that normal seedbed preparation using disc implements does not result in many *C. draba* root fragments of less than 5 cm in length and that most fragments are much greater than this unless intense secondary cultivation is undertaken (Harradine, personal observation). Tine cultivation implements would be expected to reduce fragment length even less.

From the above experimental data, cultivation of a well-established C *draba* infestation to 10 cm depth for an autumn sowing of a field crop could result in a *C. draba* population of over 5,000 plants per square metre within 4 weeks of cultivation, from regrowth of root fragments alone.

Table 1. Mean shoot number per fragment and percentage of C *draba* root fragments that had produced shoots at four and twenty-six weeks after planting.

Thickness class[a]	Length (cm)	Depth (cm)	Shoot no. per fragment		Percentage of fragments with shoots			
			4 weeks	26 weeks	4 weeks		26 weeks	
1	5	2	0.11	0.40	5.7	(13.8)[b]	20.0	(26.6)
1	5	5	0.11	0.22	11.4	(19.7)	22.8	(28.5)
1	5	10	0.09	0.14	8.6	(17.0)	14.2	(22.2)
1	10	2	1.06	1.22	48.5	(44.1)	62.8	(51.8)
1	10	5	0.83	0.91	48.5	(44.2)	54.2	(47.4)
1	10	10	0.54	0.60	31.4	(34.1)	37.1	(37.5)
2	5	2	0.80	0.86	40.0	(39.2)	45.7	(42.5)
2	5	5	1.00	1.14	69.0	(56.2)	74.2	(59.4)
2	5	10	0.20	0.37	20.0	(26.6)	34.2	(35.8)
2	10	2	1.80	1.97	71.4	(57.6)	80.0	(63.4)
2	10	5	1.77	1.86	80.0	(63.4)	82.9	(65.6)
2	10	10	0.66	1.14	40.0	(39.2)	74.3	(59.5)
3	5	2	1.06	1.06	31.4	(34.0)	31.4	(34.1)
3	5	5	0.71	0.71	20.0	(26.6)	20.0	(26.6)
3	5	10	0.09	0.14	5.7	(13.8)	8.6	(17.2)
3	10	2	0.71	0.71	20.0	(26.6)	20.0	(26.5)
3	10	5	0.74	0.74	20.0	(26.6)	20.0	(26.6)
3	10	10	0.54	0.74	22.9	(28.5)	31.4	(34.2)
l.s.d. (P=0.05)			0.32	0.27		(13.2)		(16.1)

[a] Thickness classes

1: "Thin, non-lignified": Approx. diameter 1-3 mm, fresh weight 0.14-0.30 mg/mm. (13% of total simple on fresh weight basis).

2: "Thick, non-lignified": Approx diameter 3-6 mm, fresh weight 0.30-1.00 mg/mm. (33% of total simple on fresh weight basis).

3: "Thick, lignified": Approx diameter 3-8 mm, fresh weight 0.724.20 mg/mm. (54% of total simple on fresh weight basis).

[b] Figures in parentheses are the transformed values to which the l.s.d. applies.

This experiment confirms local field experience that cultivation for field crop establishment would be expected to exacerbate an existing *C. draba* weed problem. It also indicates that normal cultivation alone is unlikely to control *C. draba*. This is confirmed by experiments which found that 39 (3) and 22 to 24 (7) cultivations over a three-year annual cropping program were necessary for *C. draba* control.

If cultivation is to be used to reduce *C. draba* density in an integrated control program it should be aimed at chopping roots into fragments as small as possible and burying them as deeply as possible.

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EFFECT OF BURIAL DEPTH ON DOCK ROOT REGROWTH

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Summary. Regrowth of broad-leaved dock, *Rumex obtusifolius*, and curled dock, *R. crispus*, from root fragments was studied. Shoots developed more readily from crown material than from taproots, and more shoots emerged from shallow planting depths. In broad-leaved dock, the ability of taproots to send up aerial shoots, and the size of those shoots, depended on depth of burial of the taproots, and on the medium they were growing in. Under the conditions of these experiments, burying taproots 20 cm deep reduced, but did not stop them sending up shoots. Suggestions for improved experimental technique are made.

INTRODUCTION

Broad-leaved dock, *Rumex obtusifolius*, and curled dock, *R. crispus*, are problems in pastures (6), and in crops farmed without pesticides in New Zealand, and in Britain (1). In New Zealand, plants regrowing from roots adversely affect yields during the cropping phase of rotations (6). Cultivated fallows are the most commonly suggested method for the cultural control of docks (1), but we have found this less effective for dock control than for couch, *Elytrigia repens*. The regrowth ability of dock roots has been studied in New Zealand (4) and Britain (5). Only the upper 7.5 cm of broad-leaved dock root and the upper 4 cm of curled dock root can give rise to shoot buds (4). Work on couch in both America (8) and Europe (3) showed that the ability of buried rhizome fragments to regrow depended both on fragment size and depth of burial. Broad-leaved dock roots buried 20 cm deep by ploughing can produce vegetative stems from that depth (2). The studies reported here were preliminary attempts to examine the effects of burial of root fragments on the speed and vigour of shoot emergence.

METHODS

Roots of broad-leaved dock and curled dock were collected in the field in early December from mature plants which were in flower or beginning to flower. In three experiments, tap roots (including crowns) or parts of roots were buried horizontally in either soil (Manawatu silt loam) or sand in 4.5 litre black plastic bags, which were then placed outside and watered regularly. In Experiment 1, root systems of *R. obtusifolius* were separated into crowns (upper 2.5 cm of tap root), main tap roots (7.5 cm long, taken from below crown) and secondary tap roots (7.5 cm long), and those of *R. crispus* were separated into crowns and main tap roots. On 3 December 1992, four units of each part were buried in each bag, in either moist soil or sand, at a depth of 5, 10, 15 or 20 cm. The 40 treatments were unreplicated and arranged at random. Experiment 2 was planted on 7 December, and Experiment 3 on 14 December 1992. In these two experiments, each root unit, the intact uppermost 8 cm of taproot (including crowns) of *R. obtusifolius*, had its volume measured by water displacement, and a sample of units was dried to constant weight. Four such units were buried in each 4.5 litre black plastic bag, in moist soil or sand, at 5, 10, 15 or 20 cm depth. In these two experiments, each treatment was replicated 7 times.

Experiment 1 was destructively harvested on 18 January, 46 days after planting. Experiment 2 was harvested on 22 January, also 46 days after planting, and Experiment 3 on 9 March, 85 days after planting. At these final harvests, emerged and unemerged shoots were counted. In Experiments 2 and 3, the dry matter of each root and its attached shoots was also assessed.

RESULTS AND DISCUSSION

In Experiment 1, the average volume and dry weight of curled dock crowns was 14.6 cm^3 and 2.7 g, of curled dock taproots was 13.5 cm^3 and 1.9 g, of broad-leaved dock crowns 23.8 cm and 3.9 g, and of broad-leaved dock taproots 13.5 cm^3 and 2.4 g.

In Experiment 1, numbers of shoots at final harvest were similar in both soil and in sand. Although the treatments were not replicated, so that statistical analysis was not possible, more shoots emerged from crowns than from taproots (Table 1). No shoots at all emerged from secondary taproots.

Table 1. Experiment 1. Numbers of shoots emerged (per planted root fragment) above soil surface at final harvest, averaged over both planting media and 5 and 10 cm planting depths.

	curled dock	broad-leaved dock
Crowns	2.2	1.7
Taproots	1.2	0.6

As shown in Table 2, fewer shoots emerged from the more deeply buried crowns, but the shoots not emerged at that time could have emerged later.

Table 2. Experiment 1. Numbers of shoots per planted crown at final harvest, averaged over both dock species and both planting media.

Planting depth (cm)	5	10	15	20
Emerged	1.9	1.9	0.9	0.3
Unemerged	0.1	0	0.9	0.9

At the final harvests of Experiments 2 and 3, the numbers of emerged shoots declined with increased depth of taproot planting (Table 3). More shoots emerged from roots planted in sand than from those planted in soil, and this difference was particularly marked in Experiment 2. At the time of harvest of Experiment 2, there were also more unemerged shoots in sand than in soil, especially at the greater depths. Few unemerged shoots remained by the time Experiment 3 was harvested, suggesting that the shoots still unemerged when Experiment 2 was harvested may have died without emerging.

Mean dry matter of roots and associated shoots at harvest in Experiments 2 and 3 are shown in Fig. 1. In both experiments, dry weights of plants from more deeply planted roots tended to be lower, presumably because of the extra resources needed for shoot emergence from depth.

Table 3. Numbers of emerged and unemerged shoots present at final harvests of Experiments 2 and 3. For all least significant differences (l.s.d.), p = 0.05.

	Planting depth (cm)					Planting medium		
	5	10	15	20	l.s.d.	soil	sand	l.s.d.
Emerged shoots per planted root								
Experiment 2	1.9	1.8	1.5	1.2	0.43	2.5	0.7	0.32
Experiment 3	2.0	1.8	1.1	1.0	0.42	1.8	1.2	0.03
Unemerged shoots per planted root								
Experiment 2, soil	0.4	0.7	1.1	2.0				
sand	0.7	2.0	3.5	4.0	0.17			
Experiment 3	0.02	0.24	0.44	0.81	0.454		not significant	

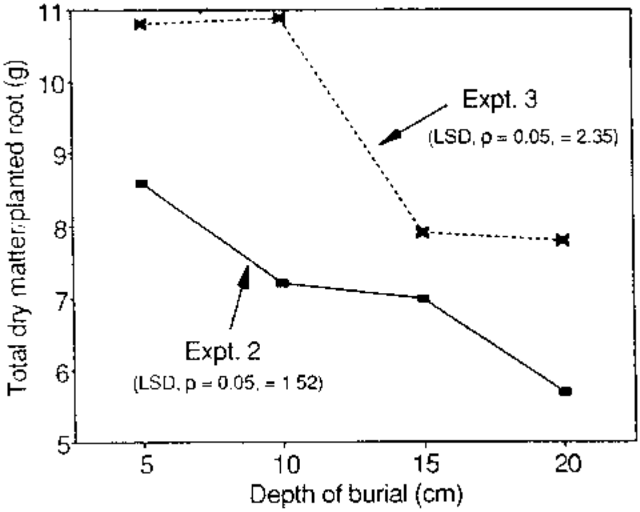

Figure 1. Dry matter of dock plants (roots and shoots) per planted root at harvest of Experiments 2 and 3.

Sand grown plants tended to show more red colouration and had smaller leaves and flowers than those grown in soil, besides having lower dry weights. Differences in growth in sand and soil may have been due to nutritional, moisture or temperature effects. Numbers of shoots emerging from roots in the two media may also have been affected by moisture or temperature, or by the differences in their physical characteristics.

In some plastic bags, especially those containing soil, shoots from deep planted roots often grew up between the soil and the sides of the bag. This may have been due to light penetrating where the soil shrunk away from the sides of the bag, or to this being an easier route for shoots to follow. A better technique may be to bury dock roots in the ground and observe their regrowth.

The evidence presented here suggests that burial as deep as 20 cm slows the growth and development of regrowth from dock roots, but it does not prevent roots from regrowing. Even deep ploughing and burial of dock roots is therefore unlikely to give adequate control. However, more work is needed on the effects of burial on dock root regrowth, because of possible deficiencies in the experimental techniques used here.

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WEED SEED EXCRETION BY SHEEP - TEMPORAL PATTERNS AND GERMINABILITY

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Summary. Duration and rate of weed seed excretion by sheep was measured. Excretion of cutleaf mignonette, *Reseda lutea*, seeds began within 24 h of ingestion, peaked between 3 and 4 days and then declined until the last seed was detected on day 12. Recovery of ingested seeds was 23%. Excretion of silverleaf nightshade, *Solanum elaeagnifolium*, seeds also began within 24 h, with most seeds excreted in the first 7 to 9 days. Single seeds were detected 23 and 31 days after ingestion. Excreted seeds of both species were germinable. Sheep were clearly shown to be potential vectors for seeds of both species. Current common on-farm quarantine periods of several days are inadequate. Stock should, where practical, be quarantined for at least 14 days to reduce the risk of spreading undesirable weed seeds. Further research on feed rations and purgative treatments may be useful in reducing excretion duration.

INTRODUCTION

Cutleaf mignonette and silverleaf nightshade are major perennial weeds of arable areas of South Australia which can survive grazing, cultivation, drought and most herbicide applications. There are no easy control measures for large infestations so emphasis must be placed on reducing their rate of spread. Strong circumstantial and anecdotal evidence of spread via seed excreted by sheep during pasture phases of ley rotations has been recognised by the authors. Four experiments were conducted in South Australia to determine the potential of grazing sheep as vectors for seed of both species.

METHODS

Experiment 1. This experiment was conducted to measure the rate, duration and germinability of cutleaf mignonette seed excreted by sheep. Seven penned sheep were each fed 7000 seeds and then a diet of oaten hay (800 g/day) and dry pellets (800 g/day). Dung was collected daily for 25 days from a collection bag attached to each sheep. Total seed excretion was measured daily for each sheep and germination (10/20°C for 12/12 h; dark) was measured every second day.

Experiment 2. Fresh sheep dung was collected fortnightly from a volunteer mallee pasture infested with silverleaf nightshade. Seeds/500 dung and berries/m^2 (mature and green) were counted at each sampling date. Silverleaf nightshade density declined from 3.5 shoots/m^2 in mid-January to zero in early May. The stocking rate was 1 sheep/ha for the first sampling date, then an average of 2.5/ha for the remainder of the experiment. Silverleaf nightshade was the only significant source of green forage present from November to May. Excreted and field-collected seeds were incubated in fluctuating light and temperature conditions (dark/light at 10/30°C for 12/12 h) to measure germinability.

Experiments 3 and 4. In Experiment 3 ten sheep were removed from a silverleaf nightshade-infested volunteer pasture in late February and placed in a pen with a concrete floor. Excreted seeds were counted in fresh 500 g dung samples which were collected every second day from the concrete floor for 17 days. The sheep were each fed approximately 1 kg of medic hay daily, and dung was swept from the floor after each sampling time. Experiment 4 was conducted with similar methodology to Experiment 3, except that 1 kg dung samples were collected for 31 days, commencing in early April.

RESULTS AND DISCUSSION

Experiment 1. Excretion rate and duration are shown for cutleaf mignonette in Fig. 1. Germination of excreted seeds two days after ingestion was only 0.8%, compared to 3.0% for uningested seed, reflecting the high dormancy level of the freshly-harvested seed. "Soft" seed may have been digested prior to excretion, thus reducing the germinability of excreted seed. Germination rose to 3.2% for excreted seed after outdoor weathering for three months. An average of 23% of ingested seed was recovered after excretion.

Experiment 2. Silverleaf nightshade seed excretion, germinability and field berry density for Experiment 2 are shown in Figs 2, 3 and 4.

Experiments 4 and 5. Silverleaf nightshade excretion for Experiments 4 and 5 are shown in Figs 5 and 6.

These experiments have demonstrated that sheep eat silverleaf nightshade berries under field conditions, and that weed seeds can be excreted for at least 31 days after ingestion. Viable and germinable seeds of both species were excreted.

In Experiment 1 cutleaf mignonette seed excretion began within 24 h after ingestion and peaked between 3 to 4 days after ingestion. After day 4 there was a steady decline and the last seed was detected on day 12 (Fig. 1). The low, but significant germination of excreted seeds confirmed a report from Ozer and Hasimoglu (2) in Turkey that excreted cutleaf mignonette seed retained some viability.

In Experiment 2 seeds were found in the dung of sheep grazing under field conditions from mid-January until late April (Fig. 2). The highest numbers were found between late January and mid-March. The highest concentration was equivalent to 672 seeds/kg of fresh dung, during the period when green berries were abundant (Fig. 4) and pasture reserves were lowest. Fig. 4 shows a decline in berry density during late summer and autumn, presumably caused by sheep grazing. The occurrence of seeds in dung ceased about two weeks after berry density had declined to zero (Figs 2 and 4). It appears that grazing pressure on berries increases as alternative feed reserves decline, leading to ingestion of almost all berries present. This pattern, observed in 1991 near Cleve, might be different in other seasons or areas where alternative feed reserves vary.

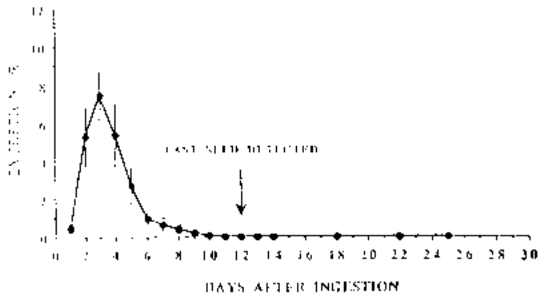

Figure 1. Cutleaf mignonette seed excretion (% of ingested) in Experiment one.

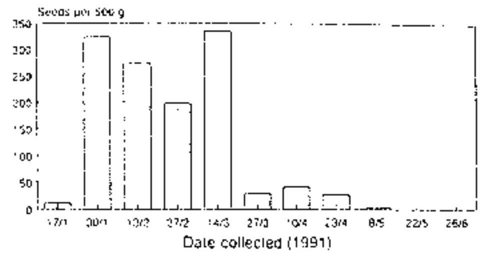

Figure 2. Silverleaf nightshade seeds (per 500 g dung) in Experiment 2.

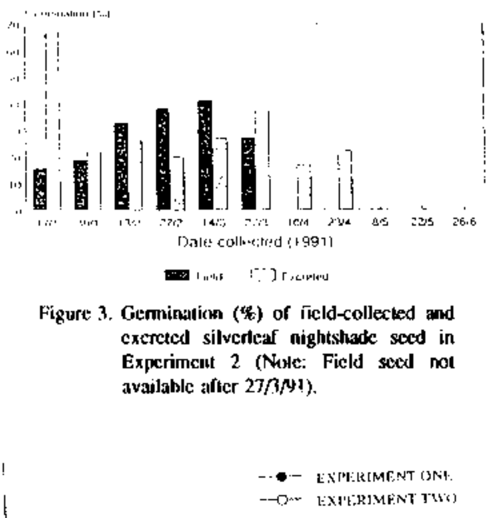

Figure 3. Germination (%) of field-collected and excreted silverleaf nightshade seed in Experiment 2 (Note: Field seed not available after 27/3/91).

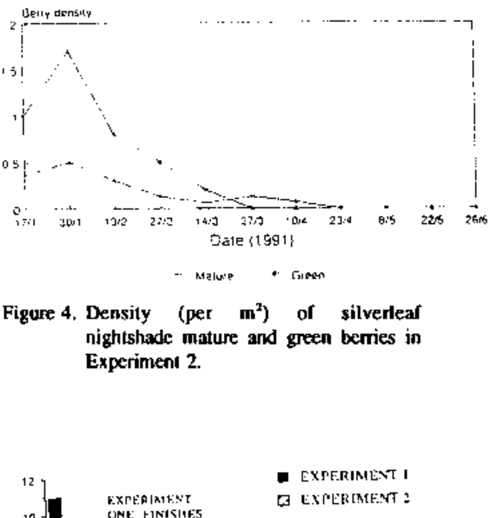

Figure 4. Density (per m^2) of silverleaf nightshade mature and green berries in Experiment 2.

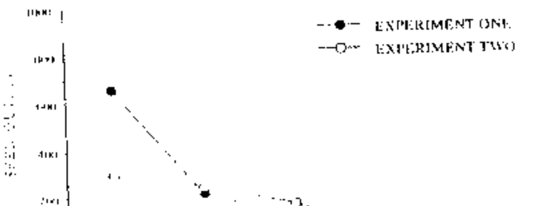

Figure 5. Number of silverleaf nightshade seeds excreted from day 1 to day 9 in Experiments 3 (per 500 g dung) and 4 (per kg dung).

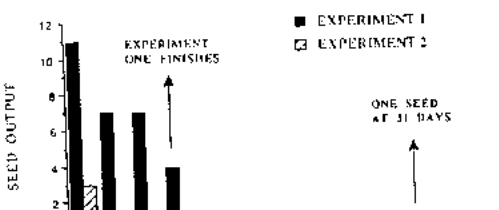

Figure 6. Number of silverleaf nightshade seeds excreted from day 11 to day 31 in Experiments 3 (per 500 g dung) and 4 (per kg dung).

Seeds collected from dung in Experiment 2 had a germination percentage of between 18-67%. Germination occurred at all of the sampling times at which sufficient seed was recovered to perform the test (Fig. 3). Germination percentage was initially high, but declined to about 20-30%. Uningested field-collected seeds had a higher germination percentage than excreted seed (Fig. 3). It is likely that "soft seed" (low dormancy) would be digested, unless excreted quickly. As a result it would be expected that excreted intact seeds would have a higher level dormancy than fresh seed samples which still contained the "soft seed" component, leading to a lower germination percentage. McKenzie (1), in a similar study, found that germination of excreted seed was higher than normal seed. The reason for this discrepancy is not known, but may be a function of the dormancy status of the normal seed. Subsamples of dung from the late January collection were incorporated into the top 5 cm of pots of sand and placed outside (Adelaide) to weather without supplementary watering. In July 1992, healthy silverleaf nightshade seedlings in the four-leaf stage were observed. This demonstrates that silverleaf nightshade seedlings can establish from within intact dung pellets. The authors have also recorded seedlings of cutleaf mignonette growing from within sheep dung under field conditions.

Experiments 3 and 4 show that seed excretion declines over a period of at least 31 days after silverleaf nightshade is ingested (Figs 5 and 6). The majority of seed was excreted within the first 7 to 9 days, but significant numbers were excreted 15 to 17 days after ingestion. The single seed detections at day 23 and day 31 (Fig. 6) may be of little practical significance in most situations. In a similar study McKenzie (1) found that sheep excreted silverleaf nightshade seeds for at least six days after ingestion, but measurements were not taken after 7 days. Their study found that almost all seed was excreted within 4 days. A difference in diet may account for this variation. St-John Sweeting (3) reported similar temporal patterns of weed seed excretion from horses to those found for cutleaf mignonette and silverleaf nightshade.

This research highlights the potential role of sheep as vectors for cutleaf mignonette and silverleaf nightshade spread. It appears that sheep will eat silverleaf nightshade berries for as long as they are available if alternative pasture reserves are low. Cutleaf mignonette seed (1320 seeds/kg dry dung) has also been detected in field-collected sheep dung by the authors (Heap, unpublished data). If sheep have been grazing in a field which contains viable seeds of either species then it would be prudent to assume that they may be excreting viable seed. If they are to be moved to an area with little or none of the weeds, then they should be quarantined for at least one week and preferably two weeks. Even after two weeks there is a small chance of spreading viable seeds. The inconvenience of quarantining sheep should be regarded as an insurance premium. The greater the time of quarantine, the less is the risk of spreading viable seeds.

ACKNOWLEDGMENTS

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PROGRESS IN TRAINING AGRICULTURAL CHEMICAL USERS IN AUSTRALIA

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Summary. It is essential that all users of agricultural chemicals are competent. At the 1987 Australian Weeds Conference, Kent and Pratley recommended the introduction of co-ordinated, industry based, national training programmes for all those who use, sell, or give advice on the use of farm chemicals. They also recommended changes to legislation to promote uniformity and remove confusion. Considerable progress has been made since 1987. The Agricultural and Veterinary Chemicals Association of Australia Ltd (AVCA) has introduced, through its Agsafe division, an industry, self-regulatory programme requiring the accreditation of storage premises plus the training and accreditation of staff. The National Farmers Federation, in conjunction with the Rural Training Council of Australia, has introduced a nationally co-ordinated training programme for the users of farm chemicals. Urban pest controllers are now required to be trained and licensed. Legislative changes have been introduced. Despite these advances many challenges continue to face our industry. Legislation controlling national registration of agricultural chemical products must be fully implemented. Training and accreditation continues to require co-ordination and rationalisation. Individuals and the Weeds Science Societies have a responsibility to support and participate in training and accreditation to ensure high levels of competency in the industry and to maintain the progress that has been made. Community and environmental pressures will force further progress unless we, as an industry, continue to take the initiative.

INTRODUCTION

Agricultural chemicals are an important component of economic and effective pest control and their continued use is essential. However, it is vital that these products are used accurately and safely to ensure effective and efficient control of pests, safety to operators and consumers, and safety to the environment.

To maximise the advantages of using agricultural chemicals while minimising potential problems we must ensure they are used correctly and only by well trained and competent applicators (3).

At the 1987 Australian Weeds Conference, Kent and Pratley recommended the introduction of co-ordinated industry based, national training programmes for all those who use, sell, or give advice on the use of farm chemicals (5). They also recommended changes to legislation to promote uniformity and remove confusion. Considerable progress has been made since 1987, although many challenges still face the industry.

RECENT INITIATIVES

It is essential that all involved with agricultural chemicals are competent. This is best achieved through education, training and accreditation instead of harsh legislation and licensing. This approach is supported by the 1990 Senate Select Committee inquiry into Agricultural and Veterinary Chemicals in Australia (1). In line with this approach, several initiatives have been introduced in Australia.

Farm chemical industry training and accreditation. In 1988, The Agricultural and Veterinary Chemicals Association of Australia Ltd. (AVCA) introduced a training and accreditation programme for all personnel concerned with the manufacture, distribution and sale of agricultural chemicals. This programme has been evolving and now AVCA has established an independent division (Agsafe) to implement and manage industry accreditation. This requires all personnel to undertake a comprehensive training programme and pass an examination to become personally accredited. As well, all premises handling and distributing products must attain premises accreditation by ensuring storage facilities comply with an industry standard incorporating all legal requirements. To date, over 7000 staff out of approximately 10,000 have gained personal accreditation while approximately half of the estimated 1200 eligible storage premises have gained premises accreditation (L. Day, pers. comm., 1993). A significant incentive to achieve accreditation comes in the form of a Trades Practices Commission Authorisation which requires industry groups not to conduct business with companies which do not meet accreditation standards.

A feature of the new Agsafe division is that individuals and organisations committed to high standards of safety and competence can become members of Agsafe.

As part of its on-going desire to continually enhance competency standards within the industry, Agsafe is in the process of introducing advanced training modules for those already accredited. These have been developed after identifying industry competencies and job profiles, and conducting a needs analysis through a comprehensive industry survey and consultation process. This stage II training has been facilitated by a substantial government grant and is being directed by a task force of industry representatives and educators. Training modules will be written in competency based training format to comply with national accreditation requirements and will be suitable for many industry sectors to include in training programmes.

End user training. In 1991, the National Farmers Federation and the Rural Training Council Australia, moved to introduce a National Farm Chemical User Training Program (NFCUTP) to ensure all users of agricultural chemicals are competent. Although mainly directed at producers, this programme is suitable for all users of these products and experience has shown an enthusiastic response from local government bodies, nursery operators, and government organisations. The NFCUTP is based on core competencies established by a National Management Committee. In each state courses have been developed and have been implemented to comply with the national competencies. The result has been a duplication of effort and resources with 6 different courses ranging from 8 to 16 hours duration. There is also duplication of administration and management activities. Despite these inefficiencies, the programme has been well received with nearly 10,000 participants successfully gaining their certificate.

This programme is the most significant training initiative ever to be introduced in Australia and deserves our full support. It is highly recommended to all users of agricultural chemicals (4).

Other training initiatives. Significant training programs which have been introduced in recent years for specific industry sectors include:

- A Grain Protection Short Course developed by Charles Sturt University for the grain handling industry.

- State based training programmes and licensing requirements for urban pest control officers.

- A training programme in Victoria for urban herbicide users (2).
- Attention is being given to the training needs of those in positions like garden shops or specialist areas who do not see themselves fitting the mould of either the Agsafe accreditation programme or the Farm Chemical User Programme.

FUTURE CHALLENGES

All who are involved in the rural industries need to be aware of current trends and work towards meeting future challenges which will effect us all and require our attention. These include:

1. Implementation of the Agsafe stage II accreditation modules which will require close co-operation between educators and industry.
2. The National Farm Chemical User Training Program is rapidly gaining in significance. A major challenge will be to achieve co-ordination of state programmes to achieve a truly national course. Furthermore the logistics of providing a voluntary training programme to an estimated 500,000 potential participants around Australia is daunting.
3. All who are currently involved in the industry, including researchers and advisers, should demonstrate their support and commitment to industry training and accreditation by participating in these programmes and becoming accredited themselves. It is possible that in the future all will be forced to do so. Such provisions are being incorporated into legislation covering occupational health and safety and agricultural chemical use.
4. Organisations such as the Weed Science Societies have a responsibility to actively support and promote industry training programmes both in Australia and in neighbouring countries in the Pacific, South East Asia and beyond. The Societies must also lobby universities and colleges to ensure that students in their courses achieve recognised industry competencies so that on graduation they are well qualified to enter the industry.
5. While training programmes should be encouraged, their introduction must be rational and co-ordinated. We need to be wary of uncontrolled proliferation and duplication.
6. Changes to legislation are still required to ensure national and international conformity of regulations governing the transport, storage and use of agricultural chemicals. The national registration scheme for agricultural and veterinary chemicals must be ratified by our politicians so that it can be fully implemented. Again, industry organisations have a responsibility to promote this as well as contribute to the debates on product labelling and container management.

CONCLUSION

In recent years much progress has been made to ensure agricultural chemicals are used safely and accurately although many challenges still face us. As individuals and as an industry organisation we have a responsibility to use our influence and our talents at every opportunity to promote and encourage training programmes aimed at improving competency and professionalism. The full support of all is essential to maintain the progress we have made in the past six years and to meet the challenges ahead. Community and environmental pressures will force further progress unless we, as an industry, continue to take the initiative, be pro-active and provide leadership.

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THE MANAGEMENT OF WEEDS ON ABORIGINAL LAND WITH SPECIAL REFERENCE TO *MIMOSA PIGRA*

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Summary. Aboriginal land owners recognise that land degradation by weeds is unfavourable to their traditional way of life and to their efforts to become self sufficient. A large isolated infestation of *Mimosa pigra* occurs on the East Alligator River floodplain in Arnhem Land, posing a threat to the region. Control started in 1983 with the release of biological control agents followed by intermittent chemical control. In 1991 the infestation was 8,200 ha of dense to scattered plants, and chemical and mechanical control commenced on the entire infestation. Follow-up work is essential to achieve the objectives of the program.

INTRODUCTION

Weed management is becoming an increasingly important issue on Aboriginal land in the Northern Territory (NT) (2,12). About 47% of the NT is Aboriginal land or is under claim by Aborigines, either through the land rights process or through purchase of pastoral properties and subsequent conversion to Aboriginal freehold. Noxious weeds are found from the Top End to Central Australia. They cause losses in pastoral production, pollution of water supplies and degradation of the natural environment. On Aboriginal land, the owners recognise that land degradation by weeds is unfavourable to their traditional way of life and their efforts to become self sufficient.

Weeds on Aboriginal land. It is generally believed that Aborigines have occupied Australia for 40,000 years. Being hunters and gatherers, rather than farmers, the traditional Aboriginal lifestyle does not include weeding. Europeans (Portuguese and Dutch) have been visiting the Northern Territory since the 16th or 17th century (11). Macassans and other south-east Asian people may have been visiting our shores for 1200 years, so there has been ample opportunity for exotic species to be transported and become established in the north. For example, the tamarind (*Tamarindus indicus*) was introduced to Arnhem Land well before the first British exploration of the east coast (11).

It is not known when the first exotic weeds were introduced to the Northern Territory, but while weeds such as water lettuce (*Pistia stratiotes*) and needle bush (*Acacia farnesiana*) are considered to be native (6,7) they may well have been introduced prior to European settlement. Hyptis (*Hyptis suaveolens*) was found by the explorer Ludwig Leichhardt in 1845 (3). Many other weeds were introduced to Darwin in the late 1800s (7), for example, candle bush (*Senna alata*), mimosa (*Mimosa pigra*), thornapples (*Datura* spp.) and snake weeds (*Stachytarpheta* spp.).

Examples of noxious weeds which now occur on Aboriginal land include mimosa, salvinia (*Salvinia molesta*), spinyhead sida (*Sida acuta*) and hyptis in the Darwin Region, parkinsonia (*Parkinsonia aculeata*), lion's tail (*Leonotis nepetifolia*), caltrop (*Tribulus* spp.) and khaki weed (*Alternanthera pungens*) in the Katherine Region, and parkinsonia, rubber bush (*Calotropis procera*) and Athel pine (*Tamarix aphylla*) in the Southern Region.

Mimosa, in particular, poses a threat to traditional lifestyles and economic development (2). It forms dense impenetrable monocultures on floodplains (8,9) which are traditional hunting and gathering areas for magpie geese, file snakes, goannas, turtles and water lilies, access to fishing areas is prevented, tourist operations may be hampered, and pastures for cattle and buffalo enterprises on the floodplains are lost.

Responsibility for control. Aborigines have been employed for weed control in Darwin since early this century (1). However, the major issues facing weed control on their own land are funding and the enforcement of the *Noxious Weeds Act*. As is the case with other land, the responsibility for weed control on Aboriginal land is that of the owners or managers of the land. Aboriginal land owners are encouraged to control weeds but, as with other landholders, the success varies from place to place. Aboriginal land owners generally believe that funding of weed control rests with Government as they do not have the physical, financial and technical resources to control weeds. In many cases, their land is not productive in a European sense and therefore does not produce income, and the presence of weeds on their land may be the result of introductions by Europeans. This philosophy has sometimes been accepted by Government.

Apart from using their own funds, Aborigines in the NT are sometimes able to access grants from various sources. NT Government funds are spent on weed control in some key areas, for example, control of mimosa in the Daly River/Port Keats Aboriginal Land Trust and in Arnhem Land, control of lion's tail at Yarralin in the Victoria River District and control of Athel pine in the Alice Springs District. Some other landholders also receive a similar service, but the NT Government is hesitant to expand funding specifically for Aboriginal land as other landholders would expect the same treatment. There are also funds available from Commonwealth Government sources such as the Department of Employment Education and Training, the Bureau of Rural Sciences, the Australian National Parks and Wildlife Service (ANPWS) Contract Employment Program for Aborigines in Natural and Cultural resource Management, and the National Landcare Program.

Under the NT *Noxious Weeds Act* eradication or control can be enforced. This Act can be applied to Aboriginal land if it does not conflict with the Commonwealth *Aboriginal Land Rights Act*, but the *Noxious Weeds Act* has never been applied to Aboriginal land. Even if it is applied, there does not appear to be a means to enforce an action to a conclusion, because those areas which are held under Aboriginal inalienable freehold title cannot be sold, mortgaged or dealt with to recover debts for compulsory control carried out by the Government, as is empowered under the *Noxious Weeds Act*.

MIMOSA CONTROL IN ARNHEM LAND

The eastern and western extremities of mimosa in Australia are on Aboriginal land. The largest infestation in Arnhem Land occurs on the East Alligator River floodplains north of the community of Oenpelli (Gunbalanya), posing a threat to the region, in particular Kakadu National Park. This infestation started before 1983, the seed probably being accidentally brought by buffalo catchers or buffaloes themselves. Limited resources were available to control this small infestation of about 200 ha. Between August 1983 and June 1985 releases were made of seed feeding beetles, biological control agents for mimosa. Other agents are now available, but while prospects for control are promising (5), biological control has still to reach a high level of effectiveness.

In 1986 twelve Aborigines controlled isolated plants on the plain under a Commonwealth Employment Program. Dense areas were aerially sprayed with dicamba. This exercise succeeded in increasing the awareness of the local community about the mimosa problem, but its short-term nature meant that it achieved minimal control. Similar short-term, intermittent, jointly funded projects involving the Northern Land Council (NLC), the Department of Primary Industry and Fisheries (DPIF), the former Department of Aboriginal Affairs and the ANPWS took place on part of the infestation between 1988 and 1990, but the infestation at Oenpelli increased to about 8,200 ha of dense to scattered mimosa.

Control proposal. An inter-agency meeting in May 1990 resolved to develop a program to control mimosa on all Aboriginal land in the Northern Territory. A Public Environment Report (PER) was completed in April 1991 (2). The then Commonwealth Department of the Arts, Sport, the Environment, Tourism and Territories invited public submissions on this proposal and an 'Environment Assessment Report' supporting the proposal was published in June 1991.

The proposal was to control mimosa by following a five year action plan (subject to major review after three years) aimed at preventing the spread of mimosa in three key areas: the Oenpelli floodplains in western Arnhem Land, the Daly River/Port Keats Aboriginal Land Trust, and Wagait Reserve. A five year program was proposed as it was unlikely that biological control would be effective within that time. Funding for the proposal was sought from the Commonwealth under a specific grant, separate from the ongoing mimosa control program funded by the NT. In 1991/92 the Commonwealth provided a direct grant of $2 million, and in 1992/93 a further $1.046 million, for control of the Oenpelli infestation. Funding was recently committed for a further three years amounting to $3.5 million. No commitment was made for funding to control mimosa in the Daly River area and Wagait Reserve.

Responsibility for the program. An inter-agency Steering Committee has prime responsibility for the program which has been implemented by the Weeds Branch of the NT DPIF, the NLC, the ANPWS and Gunbalanya Council. A research and monitoring program is carried out by CSIRO Division of Wildlife and Ecology.

METHODS

Site preparation. In 1991, 50 km of tracks were cleared with a bulldozer and road grader to allow for ground marking during aerial application of herbicide. The tracks were carefully sited to prevent future erosion or damage to any sacred sites in the area. This latter problem was avoided by using local Aboriginal operators. Areas for herbicide storage, fuel dumps, and a waste dump were selected.

Aerial application. The dry pelleted herbicide, tebuthiuron, made up most of the herbicide applied at a recommended rate of 1.5 kg a.i./ha (9,10). It was necessary to have the work completed by December before the floodplains became too wet for tebuthiuron application, and so that vehicle access could be guaranteed.

The tebuthiuron was applied by a Bell Jetranger helicopter using an Isolair application unit in November 1991. Runs were marked using 6 m high banners attached to four-wheel drive vehicles, although large areas were flown with reduced marking where banners were hidden in the trees and in some areas marking was not possible. Calibration of the equipment was carried out twice a day and when a new batch of herbicide was opened. Some variability was found within the batches and humidity affected the rate of application throughout the day. A total of 12,436 kg of tebuthiuron (62,180 kg of Graslan®), in 194 loads, were applied at an average rate of 1.53 kg/ha. One bay, which had been treated in previous years, was treated at 1.0 kg/ha. Flying time was 115.2 hours. A follow-up application of tebuthiuron was made to approximately 2,000 ha of the leading edge in December 1992.

The foliar-applied liquid herbicide, fluroxypyr, was used to control mimosa growing in the palaeochannels and areas not treated with tebuthiuron. Fluroxypyr is effective on mimosa at 600 g a.i./ha (10). All herbicide and fuel was placed on site before the wet season and staff flew in each day to carry out the application. Applications were carried out in March and May 1992 on 1,321 ha of the project site, at outlying areas in Arnhem Land, and isolated plants scattered across the floodplain towards the boundary of Kakadu National Park.

No flagging was possible as the floodplain was inundated. A total of 789 kg of fluroxypyr (2631 L of Starane®) was applied and 57.6 spraying hours were spent in this phase of the operation. Approximately 2% of the total area could not be treated due to wet weather and shortages of herbicide. Follow-up applications of fluroxypyr were made in March and April 1993.

<u>Ground control</u>. The key to successful mimosa control is to control isolated plants surrounding and away from the main infestation. Fourteen Aborigines living at Gunbalanya have been employed for this work. Over 7% of the budget was spent directly on Aboriginal employment and this proportion will increase as the major infestation is brought under control.

The ground teams were equipped with two 4 x 4 vehicles, two trailers and four quad bikes to allow access to the area. Application equipment comprised of strong lopping shears, 9 L knapsack sprayers and appropriate safety equipment for each individual. Isolated mimosa plants were cut off close to the ground and fluroxypyr mixed in diesel was applied to the cut surface. If the plant had seeded, or if a large number of seedlings were found, tebuthiuron pellets were applied by hand over the area.

<u>Mechanical control</u>. Between October and December approximately 2,000 ha of the treated mimosa was chained using two low ground pressure D4 bulldozers.

RESULTS AND DISCUSSION

<u>Aerial application</u>. Mimosa is relatively sensitive to tebuthiuron compared to other species. Within one month after application, tip chlorosis and tip browning of the foliage of mimosa can be noted, and complete defoliation is usually obtained within three months (9). An inspection was carried out on 8 January 1992. Tip chlorosis was apparent over a wide area. A further inspection on 20 February 1992, after necrosis and defoliation had commenced, indicated that striping had occurred over most bays. It was always understood that some striping may occur (2) and that only a partial kill would be achieved in the palaeochannels as the herbicide dissolves without being absorbed. The foliar herbicide, fluroxypyr, was on site to cover this contingency. The degree of striping was greater than anticipated and was probably due to calibration errors, changes in wind direction and speed, and long runs between markers.

Application of the fluroxypyr achieved necrosis and defoliation of the mimosa. The mimosa plants that were sprayed during March were flowering and bearing green pods. Seed production may have been reduced as the herbicide generally produces visible effects within ten days. However, in areas where spraying was delayed until May, the mimosa produced mature seed. After being sprayed with fluroxypyr, most of the mimosa on the plain was either dead or dying.

Ground control. The boundary between the infestation and the woodland is longer than 60 km and there are six major drainage lines feeding the area. It took from May until September 1992 for the teams to cover the paper bark fringe and treat all mimosa plants. The rest of the season was spent on the open floodplain searching for plants and re-treating the fringe.

Mechanical control. In May 1993 the chained area which had received two applications of tebuthiuron was virtually free of mimosa. Regeneration by native grasses and sedges and the introduced para grass (*Brachiaria mutica*) which has been on the plain for at least 70 years, was occurring. Mimosa is difficult to burn, but fire has a place in control programs (9). Whether chaining is necessary is debatable, and trials are planned to test whether compaction of the mimosa fuel assists in its burning and assists in the regeneration of understorey vegetation.

Cost-effectiveness. If a decision is made to control a large mimosa infestation, there is no current alternative to aerial application of herbicides. The total cost of applying tebuthiuron to mimosa was $114/ha. These costs do not include freight or staff costs etc. Fluroxypyr application at $89.40/ha is comparable to costs in spraying mimosa with this herbicide in other areas. It is difficult to estimate the cost of losing the floodplains of Arnhem Land and Kakadu National Park to mimosa, and this program is planned to continue for five years. It is therefore too early to measure final effectiveness, but the program achieved its first year objectives.

Research and environmental monitoring. A preliminary report (4) concluded that tebuthiuron is unlikely to have a deleterious effect on aquatic fauna and suggested steps to improve the efficiency of the program.

Conclusion. The control of large areas of weeds on Aboriginal land, integrating different control methods and work teams, is possible without undue damage to the environment. The Oenpelli program was the largest single aerial application of herbicide ever undertaken in the NT, the largest single application of herbicide to mimosa in the world, the largest single tebuthiuron operation ever undertaken in Australia and probably the largest single application of tebuthiuron to a wetland environment in the world. Provided that funding for the program continues the objectives of this program on Aboriginal land can be achieved.

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BENEFITS OF A NATIONWIDE EXTENSION PROGRAMME TO BIOLOGICAL CONTROL OF WEEDS RESEARCH IN NEW ZEALAND

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Summary. The success of a 5-year nationwide biological control of weeds extension programme is evaluated in terms of agent establishment, level of community interest and support, and opportunities for enhancing research. Data from many sites have been collected. The support of collaborating organisations has allowed widespread establishment of control agents and geographical areas where agents are unsuccessful have been identified early. The programme has raised the profile of biological control of weeds projects in the community and increased client groups' knowledge and understanding of the technology. Release strategies are currently being tested in a way that integrates sound experimental design with client requirements; the results will provide data that may lead to improved success rates.

INTRODUCTION

In 1986 the Biological Control of Weeds Group of Entomology Division, DSIR (now Manaaki Whenua - Landcare Research) identified the need for an extension programme to build on existing links with the nationwide network of noxious plants officers who are appointed by local government to administer control of noxious plants. The idea arose firstly because research workers were unable to supply all the requests for biological control agents, and secondly because several weed control agents released and established in New Zealand many years previously were still of limited distribution. In some cases this was solely because insects dispersed only slowly from the original release points, which suggested that a programme of deliberate re-distribution would improve success of these agents. Even for species that spread well unaided, it is often desirable to achieve establishment in areas sooner than would occur by natural dispersal. Grindell (2) has described the cooperative extension programme currently operated by Landcare Research. This paper shows how extension work has been integrated with research projects and how the extension programme is increasing the effectiveness of biological control.

BENEFITS OF USER-PAYS

Under the cooperative extension programme, collaborating organisations (Regional Councils, the Department of Conservation, forestry companies, and Landcorp Farming Ltd) pay Landcare Research for a service that includes supplying insect biological control agents, managing release sites, collecting data and training field staff (2). Crown funding approved by the Foundation for Research, Science, and Technology (FRST) pays for research on exploration, selection and host testing of potential control agents, and impact assessment. In addition, 25% of the financial contribution from collaborating organisations supports research associated with their programme. This allows researchers to conduct work that interests or benefits collaborators but is unlikely to be funded by the Crown because it may not be of sufficiently high priority or relevance to FRST outputs. Examples of research funded in this way are studies which compare the efficiencies of different insect rearing methods, assessments of the impact of thistle crown weevil (*Trichosirocalus horridus* (Panzer)) on nodding thistle (*Carduus nutans* L.), and studies on the alligator weed beetle, *Agasicles hygrophila* Selman & Vogt.

An excellent relationship has developed between Landcare Research staff and collaborating organisations. In general collaborators greatly appreciate the programme's value and continue to give it their financial and logistical support. Close communication between research and user organisations allows Landcare Research to select projects important to users. One of their particular concerns has been the lack of data on the efficacy of biological control agents that are currently being released. Since collaborators need evidence to convince ratepayers, politicians, and management that the biological control technique is cost-effective and sound, impact information from previous projects is useful to them. Other organisations interested in a specific control project may prefer to fund research that will demonstrate the effectiveness of the control agent to be released, rather than joining the extension programme. Services received by collaborating organisations are negotiated annually and may be varied from time to time, by mutual agreement, as priorities of the organisations change. However, Landcare Research's flexibility has limitations. For example, it is not possible to provide control agents for a completely new target weed without obtaining additional funding or re-organising research priorities, but it may be possible to replace a previously agreed agent by another. By responding to the needs of the collaborators, the research effort is well focused, and users willingly provide both practical and political support to gain funding for the work.

EFFECTIVE ESTABLISHMENT OF BIOLOGICAL CONTROL AGENTS

The extension programme has enabled establishment of control agents to be achieved at many widely distributed release sites much more rapidly than would have been previously possible (Table 1). Noxious plants officers, with their extensive knowledge of local weed populations, have been invaluable in identifying suitable sites for releasing agents. Traditionally, releases of biological control agents were local and limited. Cinnabar moth (*Tyria jacobaeae* L.), first released in 1929, was still restricted to the southern part of the North Island in 1981 (7). Ragwort seedfly, *Botanophila jacobaeae* (Hardy), was released at fewer than 10 sites, and St John's wort beetle, *Chrysolina hyperici* (Förster), at close to 40. While ragwort seedfly is still confined to a limited area of the central North Island, St John's wort beetle rapidly became established on St John's wort (*Hypericum perforatum* L.) throughout New Zealand (3). This demonstrates that some species can establish widely from a small number of releases. After redistribution under the extension programme, cinnabar moth is now established at sites throughout New Zealand (8). Besides providing a large number of initial release sites, the extension programme also encourages and trains field staff to redistribute insects from these primary release sites once they are well established. This further increases the effectiveness of establishment.

Perhaps an even greater problem was the previous lack of resources to assess establishment at large numbers of widely dispersed sites which meant that many release sites were not subsequently monitored (6). The extension programme has greatly increased the quality of monitoring. Data are collected on standard recovery sheets, which have been designed so that a range of observers can provide reliable information. Field staff employed by collaborating organisations are taught the skills required to complete these assessment forms.

In general, by removing the costs of rearing and establishing control agents from the research programme, the extension programme allows research to focus on the problem of identifying factors that influence success or failure. Information gathered from ragwort flea beetle (*Longitarsus jacobaeae* (Waterhouse)) and cinnabar moth release sites showed that establishment was achieved at 75% and 35% of 106 sites respectively (8). Rates of spread, as well as establishment, were greater for ragwort flea beetle. There was also a strong indication that ragwort (*Senecio jacobaea* L.) populations were declining at most sites where ragwort flea beetles, alone or together with cinnabar moth, were established. Establishment data for gorse spider mite (*Tetranychus lintearius* Dufour) releases showed that after 2 years of widespread release, mites had failed to establish in several discrete areas. Identifying the establishment pattern enabled new strains of spider mite to be sought from areas of Europe better matched climatically with those areas where the original strain failed to establish (4). Without the comprehensive and simultaneous establishment data provided through the extension programme it would have taken significantly longer for the pattern to become apparent.

Information from the extension programme benefits research projects on the biology and impact of control agents because it aids selection of optimal sites for more detailed experimental work. Field staff from collaborating organisations sometimes help to collect data for these studies. A current example involves a large-scale experiment to test release strategies. A post-doctoral fellow from the Centre for Population Biology, Silwood Park, UK, is collaborating with Landcare Research to determine how numbers of agents per release and numbers of releases per site affect establishment success. This work will be conducted in conjunction with the extension programme, so that recovery information can be collected in the normal way, but more releases will be made to fulfil the needs of the scientific objectives as well as those of the collaborating organisations. The cost of extra releases is more than compensated for by the savings to the research programme.

Table 1. Number of insect releases made under the cooperative extension programme up to 1993

Species	1986-7	1987-8	1988-9	1989-90	1990-1	1991-2	1992-3	Total
Alligator weed (*Alternanthera philoxeroides*)								
*Agasicles hygrophila**							3	3
Vogtia malloi		10	3		1	1	1	16
St John's wort (*Hypericum perforatum*)								
Chrysolina quadrigemina					4			4
Californian thistle (*Cirsium arvense*)								
Lema cyanella					3	4	6	13
Altica carduorum					2		1	3
Nodding thistle (*Carduus nutans*)								
Trichosirocalus horridus		2	26	16	22	21	11	98
Urophora solstitialis				1	6	6	1	14
Ragwort (*Senecio jacobaea*)								
Tyria jacobaeae		43	12	27	36	22		140
Longitarsus jacobaeae	10	33	25	5	6	9	4	92
Gorse (*Ulex europaeus*)								
Tetranychus lintearius				139	88	9	15	251
Sericothrips staphylinus					16	85	96	197
Agonopterix ulicetella					6		13	19
Cydia succedana							6	6
Broom (*Cytisus scoparius*)								
Bruchidius villosus						3		3
Total number species reared	1	4	4	5	11	9	11	14

* Original releases of *Agasicles hygrophila* were made at 34 sites under an earlier scheme.

BENEFITS FROM COMMUNICATION AND PUBLIC RELATIONS

About 90 noxious plants officers are employed by Regional Councils to implement weed control policies. Noxious plants officers are trained in biological control of weeds during their formal training programme. Like other field staff from all collaborating organisations they participate in workshops and field days held by Landcare Research. High-quality information supplied by Landcare Research through regular newsletters and personal contact is greatly appreciated by collaborating organisations. Their field staff now form an integral part of the biological control of weeds programme. They help to raise the profile of biological control in the community by organising local publicity and by communicating with local councillors and the public. In several areas noxious plants officers have successfully encouraged local schools to rear biological control agents for release. This develops an interest among children, their parents and their teachers in the principles and practicalities of biological control of weeds. In addition these groups identify with biological control activities being undertaken in their local areas.

Information obtained by Landcare Research from contact with field staff includes useful anecdotal observations. Information on damage to weeds by pathogens or insects observed by, or reported to, field staff may result in the identification of organisms new to New Zealand. For example, many records of the spread of blackberry rust (*Phragmidium violaceum* (Schulz)) in New Zealand have been obtained from noxious plants officers. When information on weed status or insect establishment is required, Landcare Research achieves a high level of returns from field staff because of the excellent relationship developed with them. For example, a student supported by Landcare Research surveyed noxious plants officers in the northern part of the North Island for information on alligator weed, *Alternanthera philoxeroides* (C. Martius), and alligator weed beetle and achieved a 96% return from her questionnaire.

DISADVANTAGES AND PROBLEMS

Although the requirements of research and extension are often the same - both sides want to select the best site to achieve establishment and long-term survival of control agents - inevitably some conflicts arise between the scientific requirements of the biological control project and the needs of collaborating organisations, particularly when the supply of agents is limited. Releasing insects on a pragmatic basis is rarely compatible with achieving a properly replicated experimental design.

The extension programme was first negotiated in 1986 to achieve the release of 17 species of control agent over a 5-year period. Perhaps inevitably, the proposed programme was ambitious and it has been a struggle to fulfil the original commitments. The availability of new control agents is difficult to predict in advance. It depends both on the ease with which Importation Impact Assessments can be completed for agents that successfully meet increasingly stringent safety criteria and on the technical difficulties of rearing large numbers for distribution. When local government was re-organised in 1990 the programme was re-negotiated and some of the original objectives were modified.

Information on recovery sheets has been transferred to a PC-based database, which is invaluable in providing a comprehensive record of the status of control agents at release sites. Such a large database can easily become unwieldy, so it has been important to ensure that every piece of information collected is essential and is in a readily usable form. It is costly to store information that is unnecessary.

The number of species being reared in any one year tends to increase (Table 1). It is difficult to cease rearing any species once widespread release is complete because requests for additional releases continue to be made as new organisations join the programme and priorities of organisations change.

CONCLUSIONS: THE FUTURE

The biological control of weeds extension programme has been extremely worthwhile. The level of support for the work in the community has increased, and widespread establishment of control agents has been achieved more rapidly than would have occurred otherwise. Useful information on establishment has been obtained, and new funding has been made available for research. However, only limited conclusions can be drawn about factors influencing establishment and impact of agents because scientifically designed and replicated release strategies were not used.

In the future, increasingly stringent requirements for the scrutiny of new introductions will probably reduce the number of control agents available for the programme and there will be an increasing focus on developing strategies for managing control agents. Programmes will be more closely tailored to the requirements of individual organisations and regions. Already distinct differences are appearing in programmes being run in different parts of the country in response to differing needs. Attempts will be made to implement release strategies that allow statistical comparisons of releases while still maintaining compatibility with the needs of collaborating organisations.

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TOWARDS A NATIONAL APPROACH TO EFFICIENT PESTICIDE USE

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Summary. The National Strategy for Ecologically Sustainable Development requires that Governments *assess the merits of setting indicative national targets for the use of selected agricultural and veterinary chemicals.* These words provide agricultural and veterinary scientists from all disciplines with an opportunity to contribute to debate on this matter, the outcome of which could have profound implications for Australian agriculture. Failure by any group or discipline to take up the opportunity incurs the risk that decisions will be made without their input. This paper describes the environment in which the debate will take place and outlines the role that weed scientists may play in it.

INTRODUCTION

The National Strategy for Ecologically Sustainable Development (ESD) (4) identifies five objectives for the agricultural sector, one of which covers effective and safe management of pesticides. A key strategy for achieving this objective requires that Governments *assess the merits of setting indicative national targets for the use of selected agricultural and veterinary chemicals.*

Given the political dimensions and the policy ramifications of this statement it is imperative that agricultural and veterinary scientists from all disciplines contribute to a rational and informed debate on the issue, weighing the opportunities and potential benefits against the costs. Failure to take up the opportunity incurs the risk that vital decisions will be made in the absence of appropriate input from weed scientists.

TREATMENT OF PESTICIDE IN THE ESD PROCESS

The Commonwealth Government's Working Party that reported on ecologically sustainable development in the agricultural sector (1,2) recognised the concerns expressed by different interest groups about pesticides, including such matters as: consumer health and the safety of workers and people in rural areas; the environmental impact of pesticides in soil and water; and the development of pesticide resistance.

It is clear, however, that the overriding concern was for the need to maintain market access, something that could be jeopardised were Australia to export commodities containing residues of pesticides that are either not approved for use or exceed maximum residue limits in importing countries. This concern is reflected in the recommendation *that targets be set for reductions in use of specific classes of chemicals as a means of encouraging the development of alternatives and ensuring that Australia is in a position to meet changing market requirements for its agricultural products* (2).

The Working Party was not unanimous in its view on establishing targets for pesticide use; some members supported the idea of mandatory targets, others favoured the setting of indicative targets. The National Farmers' Federation (NFF), on the other hand, was opposed to setting any targets without objective scientific data to show that such action would be beneficial to human health and safety (2). Debate within the Working Party was constrained by a lack of data on the potential benefits of setting targets for pesticide use in Australia. In the end, the statement incorporated into the National Strategy viz. *Governments will assess the merits of setting indicative national targets for the use of selected agricultural and veterinary chemicals* was, in all probability, the best possible outcome. The ESD strategy now provides weed scientists with an opportunity to contribute to debate on this matter, the outcome of which could have profound consequences for our agricultural industries.

INITIATIVES TO REDUCE PESTICIDE USE

There is a worldwide trend to greater regulation of pesticide use involving, among other things, frequent reviews of registered products and the introduction of progressively more rigorous criteria for assessing the impact of pesticides on the environment. These developments have led to the withdrawal of significant numbers of chemicals from use. For other products, registered uses have been severely restricted. The level of community concern about pesticides was so great that governments in Sweden, Denmark and the Netherlands legislated to reduce their use (6). Several other countries have established voluntary programs with similar objectives (5).

It is important at the outset that Australian agricultural and veterinary scientists understand the environment in which Governments have been prepared to take what some might think to be quite radical steps or, in the case of the Netherlands, draconian measures. These steps have not been taken lightly, and reflect extensive consideration rather than hasty decisions to pacify green lobbies.

The Netherlands ranks only second behind the United States in the value of its exports of agricultural products. It has achieved this position through the development of intensive, highly sophisticated systems of production supported by large inputs of pesticides. To achieve the goal of halving pesticide use in a decade will involve massive restructuring of agriculture. Direct costs to farmers have been estimated at 2.3 billion Dutch florins (AUS$1.8 billion) and extra costs will run to an estimated annual 830 million Dutch florins (AUS$660m) in the year 2000 (3). No government could afford to alienate an important and influential sector in this way without compelling reasons and hope to survive. While doubtless there is much disquiet among farmers, it was clear to the Dutch that the agricultural systems they had in place were on a totally unsustainable course and, if the country were to retain its position in world agriculture, quite drastic measures were required (7).

The situations in Sweden and Denmark were quite different. The agricultural sector in neither country is in any way comparable with the Netherlands, yet public concern about the impact of pesticides on human health and safety and the environment were sufficient for the governments in these countries to lead the way in legislating for reductions in pesticide use (6).

The message from this is that each country must assess its own situation and set in place policies directed to pesticide use that will provide the best possible outcome for the community. This is the challenge before us.

REGULATION OF PESTICIDE USE IN AUSTRALIA

Historically, registration of pesticides in Australia has been a state responsibility. Under an agreement developed by the former Standing Committee on Agriculture (now the Standing

Committee on Agriculture and Resource Management (SCARM)), the Commonwealth undertook clearance of agricultural and veterinary chemicals ahead of the States imposing their requirements for registration and use. The role played by the Commonwealth was formalised with the introduction of the Agricultural and Veterinary Chemicals Act 1988. This is about to change and under an agreement announced in a press release by the Minister for Primary Industries and Energy in 1992, the Commonwealth will take responsibility for registration. This is to be done by a statutory body, the National Registration Authority, but the States will retain responsibility for use of agricultural and veterinary chemicals. Thus any move to establish a national approach to pesticide use will need to be considered in the SCARM arena. SCARM is pivotal because it is one of those committees where business of common interest to the States and to the Commonwealth is dealt with and where national co-ordination is undertaken.

Countries that have moved to reduce pesticide use, by legislation or voluntarily, have used the registration process as an instrument to force change by introducing progressively more rigorous criteria for assessing the impact of pesticides on the environment. If decisions were made to set targets for pesticide use in Australia, the National Registration Authority would play a key role.

Bodies such as the NFF, consumer, environmental and other interest groups will be important contributors from the outset.

A ROLE FOR WEED SCIENTISTS

Weed scientists have a particularly important role in the development of a national approach to pesticide use for several reasons: herbicides are the single most important group of pesticides in use in Australia, representing more than sixty percent of sales; herbicide use has increased as farmers have adopted minimum tillage technology; existing public concern about herbicides contaminating the environment; and the development of herbicide resistant crops will heighten debate on the use of pesticides.

It is critical at the outset that debate is a constructive one and does not degenerate into an exchange of unsupported opinion about what is possible and what is not possible and/or whether, in the view of experts, herbicides pose any or no risk to the environment or to human health and safety. Irrespective of scientific views about the safety of pesticides, serious consumer concerns exist.

With their mastery of the subject, weed scientists have an obligation to package existing information in a way that can be used by non-scientists, particularly those who must advise governments on the issues.

Recognition of the depth of public concern about pesticides and the worldwide trend to seek ways to reduce pesticide use should guide weed scientists when framing their R&D proposals. The objective for their research should be an outcome that provides Australia with substantial national advantage.

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THE ROLE OF LANDCARE GROUPS IN WEED CONTROL

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Landcare groups have played a key role in weed control in Australia. Landcare groups have provided a forum for an exchange of information between landholders and Government Departments, and have increased awareness of weed problems in the community. The groups have fostered cooperation between neighbouring properties and Government research and extension agencies.

Landcare groups have adopted a participative action research/learning approach, with demonstration sites and field days to increase landholder awareness and education of weed control methodology. Landholders on the Landcare groups are aware of the factors that may influence the adoption process of other landholders. In some cases peer pressure has been responsible for effective weed control in an area.

Weed control has been the single most important issues responsible for the formation of some landcare groups. These groups have recognised that an integrated approach is required, as weeds do not recognise property boundaries. A number of case studies are provided which describe the processes used by some Landcare groups.

Landcare groups also provide an administrative body for the application of funding from State and Commonwealth funding sources.

BACKGROUND TO LANDCARE GROUPS

Landcare groups are made up of people who have come together to collectively work towards improved land management. Groups usually consist of primary producers, members of local government, educational institutions and anyone from the local community. With limited financial and people resources, groups rely on awareness and education to promote sustainable land management practices.

The number of landcare groups in Australia grew in response to a commitment by the Australian Government to support a concerted effort by the community towards addressing land degradation. This support was brought about by the collaboration of the two key primary producer and conservation groups, the National Farmers Federation and the Australian Conservation Foundation. The result of this collaboration was funds being set aside for distribution to the community by way of grants, known as the National Landcare Program.

Issues which groups address vary between districts and states. In southern Australian salinity, feral animals, revegetation and soil erosion are key issues. Woody weeds, rangeland management and soil erosion are key issues in northern Australia, eight of the fourteen different pasture communities in Queensland are threatened by the spread of woody weeds or undesirable timber regrowth (6).

Landcare groups organise activities such as field days, guest speakers at meetings, farm walks, bus trips and project sites. Funding for projects and activities can be obtained by submissions to the National Landcare Program.

COOPERATION AND INTEGRATION

The early landcare groups which formed in Victoria aimed to address problems of weeds and salinity. Producers saw the futility of doing action on their property without the cooperation of their neighbours. Weed control will only be effective if the source of weed seed is also controlled. This is difficult if the source is on a neighbouring property. Working towards a cooperative solution also saves on human and financial costs. Landcare groups have the advantage of being able to influence their neighbours and develop a joint effort.

Government and non-government agencies, individual landholders and local communities will not only have to find new solutions to ecological problems - they must also find new ways of working together (2). Combined activities and projects have benefits for both government agencies and producer groups. Input from the community results in ownership of problems and acceptance which may lead to more effective action. Government agencies enjoy the benefits of an additional extension service and input to research projects.

<u>Dalrymple Landcare Committee</u>. The Dalrymple Landcare Committee located around Charters Towers have a close working relationship with government agencies, agribusiness and producer organisations. The Committee has links with Tropical Weeds Research Centre (Lands Department), Grazing Lands Management Unit (Department of Primary Industries) and CSIRO.

Management of woody weeds is a major issue for the Committee. At their regular field days weeds are always on the agenda. By organising field days, the Committee seeks to provide informative discussions which may minimise the costs of weed control to landholders in the Shire and surrounding districts.

<u>Prickly Acacia Landcare Project - Western Queensland</u>. Prickly Acacia is an overwhelming woody weed problem in the Mitchell Grass Downs of North West Qld which is being addressed through the efforts of four landcare groups and Lands Department. The Flinders, Richmond, MacKinlay and Cloncurry Landcare Groups submitted a combined project to National Landcare Program to appoint a prickly acacia extension officer to assist with mapping the weed and providing advice to landholders on control programs.

AWARENESS AND EDUCATION IN RURAL AND URBAN COMMUNITY

Landcare groups do not have the resources to address all the problems in their districts. A role which groups fill is in promoting available information and technology to other producers. Promoting discussion on methods of weed control plays a big part in eventual management. Bringing issues out in the open helps producers to understand their problems and perhaps be more willing to act.

Many weeds in Australia originated as urban garden weeds and escaped into the country. Road side demonstrations and trials set up by landcare groups help to raise awareness of issues and promote early control of weeds. These demonstrations also educate the urban community about issues of weed control. Hopefully it will serve to help the community to accept responsibility for land degradation, in this case weeds.

PEER PRESSURE AND LANDHOLDER PERSPECTIVE

The primary role of landcare groups, and the measure of their effectiveness, is generating commitment to sustainability at a community and individual level (1). Commitment is achieved through helping the community to understand and own the issues of land degradation and to develop action.

Landcare groups can play a unique role in the rural community by putting pressure on other landholders to control weeds. The message is coming from landholders who have the same constraints and who are often in a similar situation. Landholders will more often listen to opinions and advice from other landholders.

Feedback to government agencies on land degradation is a role taken seriously by landcare groups. Following is an extract from a talk given at the Dalrymple Landcare Committee Rubbervine field day.

> *"Weed control on the massive scale needed in Northern Australia is too much for landholders alone.* Over zealous lands officers, departmental heads, single issue enthusiasts or stupid politicians will extinguish what hope we have if lack of understanding overshadows realism."(3)

FUNDING FOR WEED CONTROL

Only recently has funding been made available through the National Landcare Program for landcare groups to work on weed projects. Landcare groups have been instrumental in helping people to understand that weeds are land degradation.

Several projects, which were submitted for funding, from Victoria, New South Wales and Queensland, under National Landcare Program specifically related to weed control (5).

The recently released Draft National Weed Strategy stated that:

> *"Weed management should be seen as a fundamental part of landcare, because weeds are major contributors to land degradation and weed management is an important factor in sustainable land use and ecologically sustainable development (4).*

It is hoped that this statement will assist in providing more assistance in the future for weed management, financially through programs such as the National Landcare Program and also be encouragement to community groups such as Landcare and to State government departments in the fight against weeds.

Understanding and ownership of land degradation issues by the community are fundamental in successfully moving towards sustainable land management. The problem of weed control did not appear overnight and can not be solve by supply of simplistic weed destruction information. Landcare groups are attempting to addressing the issue by promoting understanding of the problem, discussing the issues and encouraging action.

Cooperation and collaboration with Landcare groups may assist in more effective methods of weed control than is possible by chipping away at the problem in isolation.

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WEED CONTROL BOARDS - DO WE NEED NON-SCIENTISTS?

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Summary. This paper gives a farmers's view of the role of non-scientists on weed control authorities. Control authorities generally comprise both scientists and non-scientists such as farmers and environmentalists.

The non-scientist board members are very necessary to project any ideas or conclusions the board makes, to the people who actually do the work.

A non-scientist board member with some tertiary education, a broad outlook, and successful in their field is ideal. You should pick, rather than elect, an individual who has worthwhile knowledge of the subject, and can communicate back to his peers. Boards should be limited to six or seven members and include a good, non-public servant chair.

INTRODUCTION

This is going to be the most non-scientific paper ever presented to a conference of this nature. It might just give you all a little light relief!

I can imagine many occasions at a meeting of a statutory weeds board where a scientist has to listen to a non-scientist talk on a problem. He may either be a farmer or may be an environmentalist. I can picture the scientist thinking to himself: "Why doesn't this nitwit shut up, he doesn't understand the subject, he is being parochial with tunnel vision, he wanders all over the place, and he is dull". One of the most difficult things for a farmer is not to relate a problem to his own situation or environment.

So why not have just scientists on boards and committees dealing with pest plants? Could they operate more efficiently and with less cost?

Prior to 1948 weed control in South Australia was overseen by Ministerial advisory committees made up of public servants. In 1948 a new Noxious Weeds Advisory Committee was appointed with two non-scientists representing local government and farmers (6).

Landowners continue to have a role in noxious weed control authorities in SA (3), Qld (7), WA (1), and in advisory committees for most other states. These boards are successful at meeting farmers needs (5).

In SA we have a two-tiered system with local animal and plant control boards whose members are appointed by local government. The Animal and Plant Control Commission is responsible on a statewide basis. It comprises seven members, six nominated by the Minister of Primary Industries, and one, being a public servant nominated by the Minister for Environment and Land Management. The Minister of Primary Industries must select at least four primary producers, and two persons from a panel of no less than four nominated by the Local Government Association with appropriate experience in agriculture and matters of animal and plant control (2).

ROLE OF NON-SCIENTISTS

So why not have just scientists on boards and committees dealing with pest plants? Could they operate them more efficiently and with less cost?

The first answer is yes, they probably could.

The next answer lies in where the weeds actually occur, which is usually either on farms, crown lands or National Parks and reserves. These lands belong to farmers or the State. In the end the landholder has to deal with the problem of weeds, and is responsible for their control and eradication (2). So therefore landholders should have some say in these boards.

These representative landowners are very necessary to project any ideas or conclusions the board makes, to the people who have actually to do the work (8). A structure which gives strong local participation and responsibility is essential for effective weed legislation (9).

SELECTION OF BOARD MEMBERS

So how do we ensure that the best possible selection is made of the person to fill this role?

I have been a farmer for most of my life, and a member of the South Australian Vertebrate Pest Control Authority and Pest Plants Commission, probably for longer than anyone else, and maybe for too long! So I have some experience of a great variety of board members.

The ideal member in my view is an educated person, preferably with a tertiary education, so that he or she has been taught to think. This person should have travelled a bit, which tends to give them a broader outlook. It is also necessary that they have been successful in what they are doing, as this gives them standing and respect in the community. They must be able to visualise problems in a wider sense than their own area. One of the things I am sick of hearing is: "Now at Oodnawallop where I live, we always do things in this way, (and he will go on to describe this at length), and I cannot see why you cannot fix the problem at Oodnawant".

People on a board must not be there just because they represent another organisation. I well remember an experience on the executive of a primary producers' organisation in South Australia, when we were asked to appoint a member to the State Abattoirs board. The discussion went something like this:-

> "Well, Richard Harvey has sheep and cattle which he sends to this abattoir, and it is his turn for another Board".

Although I eventually learnt a lot, my knowledge of running an abattoir initially was almost zero.

So you need to resist this sort of pressure, which is not always easy for a Minister of State. Instead pick an individual who has the attributes I have already mentioned, plus a worthwhile knowledge of the subject, and who can communicate with his peers.

THE CHAIR

Another concern is the selection of a board presiding officer or chair. I would prefer to see an independent chairman of a weeds authority, rather than a public servant. This is not because I dislike public servants, but usually they are combining the job with a very heavy workload from other directions, and cannot devote sufficient time to the weeds board.

The success of any meeting is largely determined by the presiding officer (4). There are many people who seem quite normal individuals at a meeting, but on being elected to the chair their whole personality changes. Because nobody can really interrupt them they talk too much, prolong the meeting, and tend to shorten the members lives through boredom. A good chairman should stop people talking, not do it himself.

BOARD SIZE

Six or seven members on a board is plenty. Resist the temptation to add people either because they want representation, or to increase the coverage geographically (4). A board of fourteen or fifteen is recommended by some (10) but in my experience is far too many, cumbersome, and difficult to handle.

I became chairman of a board like this some years ago, and the only way I could handle it to make the meetings reasonably short was to arrange to have most of the business decided beforehand, which is not a good idea.

Finally, life is very much more pleasant if every member has a sense of humour!

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DYNAMICS OF WEED INVASION: IMPLICATIONS FOR CONTROL

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Summary. While existing problem weeds receive most attention in terms of research and control, the contiued introduction of species into Australia over the last century makes it likely that many currently unimportant species will become important problems in the future. Many invasive species remain in restricted foci for long periods before undergoing explosive range expansions. Early recognition of species beginning rapid range expansion could allow early and more cost-effective control. There is a need for the development of a proactive approach to limit future weed problems.

INTRODUCTION

Weed control necessarily focusses on those weeds which cause extensive economic or environmental damage. These are the well-established problem weeds which cover large areas and are often spreading rapidly (8). There are, however, many other introduced species which can become locally abundant or problematic or remain in localised areas without necessarily becoming a weed problem. An important question to be considered is how many of the currently non-problematic introduced species have the potential to become important weedy species. An associated question is whether we have the capacity to recognise potential weed problems at an early stage and hence carry out more cost-effective control. Early recognition and treatment of problems could result in the prevention of costly invasions and control measures in the future. In this paper, patterns of weed spread are examined, the potential for future weed problems is discussed and the possibilities of developing methods of early detection of problems are explored.

PAST PATTERNS OF WEED INTRODUCTION AND SPREAD

Plant introduction into Australia has been a continuous and on-going process since the arrival of Europeans, with a near linear increase in naturalised species in all states of Eastern Australia (6,16; Fig. 1), which continues more or less unabated despite quarantine laws. Examination of the history of introduction of some of today's most important environmental weeds indicates that most were introduced some time ago (8). Further examination of the dynamics of range extension of species for which information exists illustrates that, in many cases, populations remained small and localised for long periods before a sudden explosive range expansion (1,2,3,5,12) . This corresponds to a pattern observed more widely for a range of different invading plant species, as well as for diseases (11; Fig. 2).

Combining the information in Figs 1 and 2 provides some sort of estimate of the potential for the development of further major weed problems in Australia. Lag times between initial colonisation and the explosive phase of range expansion can be as much as 70-100 years. Given that many of our current weed problems were among the earlier introductions and that the number of introduced species has increased by almost an order of magnitude in the last century, it seems likely that we can expect an increasing number of introduced species to move into an accelerated rate of spread. Since current control measures are inadequate to deal with the present suite of problem species, the prospect of an ever-increasing supply of new problems should be viewed with concern.

PREDICTION AND EARLY DETECTION OF RAPID SPREAD

Attempts to predict which invading species are likely to become important weeds have largely met with a lack of success. While a broad set of characteristics of successful invaders can be put together (14,15), this still does not provide a useful mechanism for predicting the responses of individual species (4,9,10,13). This is in part because a successful invasion depends not only on the characteristics of the invading species but also on the characteristics, dynamics and history of the site being invaded (9,10). This suggests that invasions are somewhat individualistic in nature, depending on the chance congruence of a number of plant and site factors at a particular time (4). If this is the case, predicting the onset of a rapid range spread by any one species can be expected to be a difficult, if not impossible, task. However, given the likely extent of the problem in the future, this task should receive further attention.

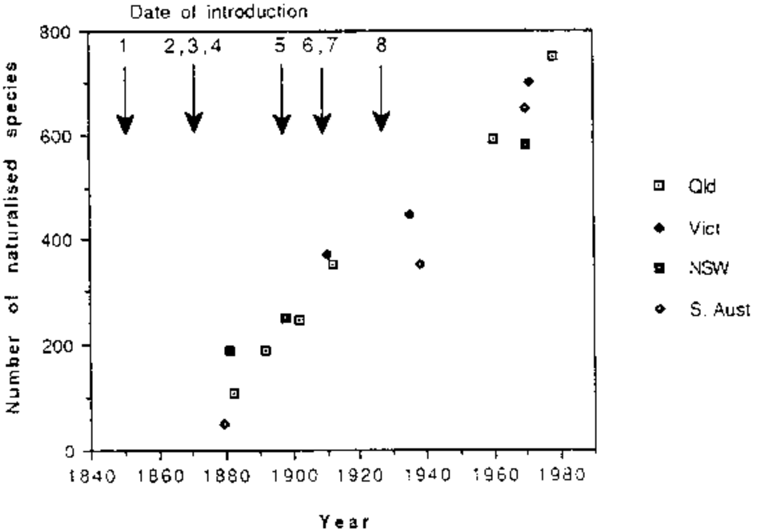

Figure 1. Number of naturalised plants in the four eastern Australian states, 1870-1980 (from 6,16), and estimated date of introduction of selected species (data from 8): 1; *Crysanthemoides monloifera*; 2, *Cryptostegia grandiflora*; 3, *Myrsiphyllum asparagoides;* 4,*Mimosa pigra*; 5, *Eichornia crassipes; 6; Parkinsonia aculeata;* 7, *Tamarix aphylla*; 8, *Prosopis* spp.

Given that it is difficult to predict which species will become problem weeds from species characteristics alone, we need to develop a predictive capability based on other factors. Early recognition of the transition to the phase of rapid spread may hold some promise. Some work has been conducted into factors which accelerate the rate of spread of invaders. For instance, spread will be more rapid if numerous widely-spaced foci of invasion develop than if spread is mainly from a single focus (Fig. 3; 11). Examples of rapid plant spread show a mixture of short-distance dispersal around a primary focus and long-distance spread to new sites, with subsequent short- and long-distance dispersal from the secondary sites (17). Monitoring for this process of the formation of widely-spaced secondary foci could provide one means of early detection of potential problems. Similarly, species which are currently present in small abundances but in many localities could also receive priority attention.

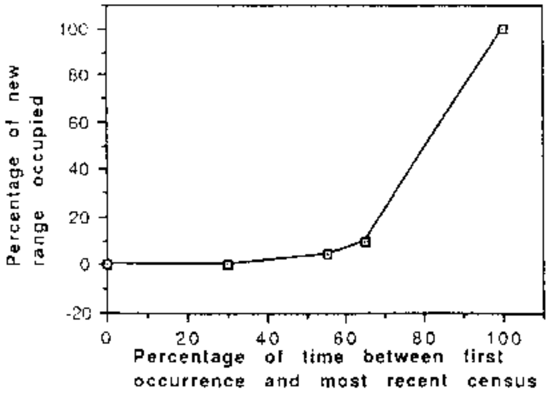

Figure 2. Stylised representation of spread of an invasive plant species plotted against the percentage of the new range occupied versus the percentage of time between first occurrence and the most recent census (derived from 11)

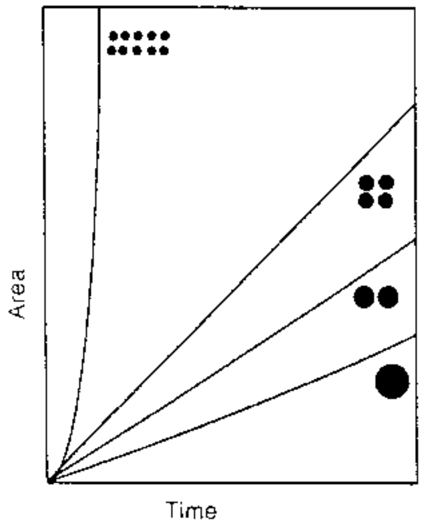

Figure 3. The addition of foci increases the rate of new range occupation quadratically, even if the total area initially occupied and rates of spread are the same (11).

The importance of multiple foci in speeding up invasion is also relevant to control programs: if the control measures centre on the primary focus and ignore smaller infestations, these will simply act as secondary foci and negate the effects of the control program. The need for early control of species not yet seen as major problems also has to be communicated to managers, who may be unwilling to divert resources from other apparently more pressing problems. A simple cost-benefit analysis of early versus delayed control on any of the exisiting major weed problems would provide a convincing extension tool.

More attention to site factors which enhance invasion potential might also be useful. Disturbance, especially, is a factor frequently invoked in permitting invasion (7), and this includes human-induced disturbances such as road building and logging, and natural disturbances such as fires and floods. While not all serious weed problems can be linked directly to disturbance, the linkage is frequent enough to provide some degree of predictability. The combination of an unusual disturbance or climatic event and the presence of multiple foci of a potential invader could be used as an early warning alert for an incipient problem.

CONCLUSION

The two approaches discussed above may provide the start of a framework for assessing and predicting potential future weed problems. However, they need to be tested and developed in practice, other approaches need to be considered, and the whole area requires more theoretical and practical research. Until now the question of predicting future weed problems has always been put in the "too hard" basket. Considering the extent and costs of current weed problems and the huge potential for future problems, a small degree of effort put into developing early warning systems now may pay huge dividends in the future, if invasions can be detected and controlled before they reach the stage of explosive spread. In addition to reactive management to deal with today's massive problems, we also need proactive research and management to minimise tomorrow's.

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THE NATURE OF EXOTIC INVASIONS IN HERBACEOUS VEGETATION OF HIGH AND LOW SPECIES RICHNESS: IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

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Summary. Sixty quadrats from grassland vegetation were divided into those with above and below average richness of native species. Low richness sites were more highly disturbed and mainly dominated by exotic perennial grasses. High richness sites were typically dominated by native perennial grasses. The most abundant exotic species showed two patterns of occurrence: greater frequency in low richness sites or similar frequency over both low and high richness. The data indicate that exotic species may vary in their impact on native vegetation, and that selective control could be a useful strategy to maintain, or regain, native species richness following disturbance.

INTRODUCTION

Combinations of disturbance and invasions by exotic species are considered to be a major threat to the survival of native plants in Australia (5). In a survey of native grassland sites on the New England Tablelands, 97% of samples were found to contain exotic species, even though the sampling was stratified to include examples of the vegetation in its most natural state (McIntyre, unpublished data). For vegetation such as natural grasslands, exotic invasions are a fact of life. The challenge in conserving the native component of such herbaceous communities lies in understanding and manipulating synthetic communities of exotic and native species.

The relationship between exotic invasions, exogenous disturbances (human-induced) and loss of native species is widely recognized in Australia (1). In field situations, it can be difficult to differentiate the direct effects of disturbances on native species from the competitive effects of exotic invasions, as well as the interactions arising from these two factors. Despite this, field observations give us direct information on the nature of exotic invasions and at least correlative evidence of the relationship between invasion, disturbance and persistence of native plants.

There is disagreement regarding the impact of exotics, with some arguing that the displacement of natives by exotics is reduced by virtue of their use of unoccupied niches. However, Herbold and Moyle (4) have argued convincingly that undisturbed communities are not invaded without disturbance or without displacement of native species in undisturbed communities. In the case of herbaceous vegetation in Australia, even after disturbance, native species would eventually recolonize in the absence of exotic propagules and it would be difficult to argue that exotics have no direct impact on native communities, given the space they occupy. Nonetheless, the relative impacts of different exotics may vary. The inevitable presence of exotics in some vegetation types makes it worthwhile considering how species may differ in the the impact they can have on native communities and whether there are some that should be targetted for control under particular circumstances. With these questions in mind, this paper compares the exotic component of species poor and species rich herbaceous vegetation and asks whether particular exotic species, life-histories or life-forms are associated with low or high species richness?

METHODS

A survey of herbaceous vegetation was conducted in grassy ecosystems on the New England Tablelands of New South Wales during 1990-91. The vegetation sampled had been subjected to varying degrees of modification resulting from exogenous disturbances, mainly grazing, soil disturbance (mostly from earth-moving equipment), water enrichment (sites receiving extra runoff resulting from human-modified drainage) and (although not measured) nutrient enrichment. Details of methods and a full species list are presented in McIntyre *et al.* (6). Of the 120 quadrats originally sampled (one 6x5 m quadrat per site), a subset of 60 ungrazed sites was taken to examine the relationship between richness of native species and exotic invasions. Due to the complexity of vegetation response to stock grazing and the interactions that are likely to occur between grazing and other disturbances, the 60 sites that had physical evidence of grazing at the time of sampling, were excluded from the current analysis.

The sample was divided into two groups of 30 sites; a low richness group, with below-average richness and a high richness group with above-average richness of native species. The average richness of the sample was 19.9 native species. Two simple measurements of floristic abundance were used: frequency (or counts) of species or groups of related species derived from presence/absence data collected for all species in the quadrats; dominance was recorded for all species that had a projected canopy cover of >10%. Although this cover rating is well below what might be considered true dominance, there was an average of only 1.6 dominant species per quadrat, and the majority of species had very low percentage cover. Each taxon was classified into an additional two categories: annual or perennial life-history and forb or grass life-form. These traits were compared over the two richness groups.

RESULTS AND DISCUSSION

The low richness group occurred in habitats with a greater frequency of soil disturbance and water enrichment (Table 1). Significant losses of native species and increases of exotics with these disturbances have been confirmed statistically for the entire data set (7). Low richness was also associated with either thick litter or >5% bare ground while high richness sites tended to have thin litter cover (Table 1). These proportions varied significantly ($\chi 2= 8.3$, d.f.= 3, $p<0.05$). The dominance of chalk grassland vegetation by perennial grasses, and their ability to suppress smaller statured, interstitial species through litter accumulation has been described by Grubb (3). A similar situation appears to occur in New England where *Poa* spp. and *Themeda australis* are the most common dominants (6). The bare ground at low richness sites was most commonly due to disturbances whereas it appeared more frequently to be due to constrained production at the high richness sites.

The two groups had similar numbers of dominants overall, although low richness sites had a greater proportion of exotic dominants and high richness sites had more native dominants. The same trends were evident in the number of non-dominant exotics (Table 2).

Perennial grasses were the most common dominants overall, although amongst exotics, annual grasses and perennial forbs were also well represented (Table 3). At high richness sites, all the dominant perennial grasses were native, while at low richness sites there were similar numbers of records of native and exotic dominant perennial grasses. Thus perennial native grasses may also be capable of reducing richness of interstitial plants in some cases. There were only four low richness sites that were dominated only by natives. Of these, none appeared to be soil disturbed, two had water enrichment and three had litter >5 cm deep. In contrast, the presence of dominant exotic plants was never associated with high native richness, except in the case of annual grasses.

Table 1. Comparison of sites with above- and below-average species richness (30 m^{-2}). Numbers of sites in each of three soil disturbances classes and two water enrichment classes are given.

Richness of native species	Soil disturbance			Water enrichment		Average number of non-dominant exotic species			
	Low	Mod.	High	No	Yes	>5% bare	<1	1-5	>5
Low (mean = 12)	5	4	21	17	13	13	1	3	13
High mean = 28)	22	7	1	28	2	9	2	12	7

Table 2. Average number of exotic and native dominant (cover >10%) taxa and exotic non-dominant taxa recorded in 30 m^{-2} plots at sites of low and high native species richness.

	Average number of dominants			Average number of non-dominant exotic species
	Exotic	Native	Total	
Low richness (n=30 sites)	0.97	0.70	1.67	8.0
High richness (n=30 sites)	0.13	1.37	1.50	4.3

Table 3. Distribution of species records across life-history categories

Life history	Native dominants		Exotic dominants		Non-dominant exotics	
	Richness		Richness		Richness	
	Low	High	Low	High	Low	High
Perennial grass	16	32	12	0	36	13
Annual grass	0	0	8	4	47	18
Perennial forb	5	7	7	0	99	61
Annual forb	0	0	2	0	56	35
Other	0	2	0	0	2	1
Total	21	41	29	4	240	128

Records of non-dominant exotics were much more frequently associated with high native richness (Table 3), with 35% of all records being at high richness sites compared with 12% of dominants. Species from all life-history categories were found to occur both as dominants and non-dominants in the plots.

Table 4 lists the ten most frequently occurring exotic taxa. They represent a range of life-histories, but all show one of two patterns of occurrence: 1) Tolerant species - these had similar frequencies at sites of low and high richness and tended to be non-dominant, perennial or annual forbs (although *Hypochoeris* spp. and *Trifolium arvense* each dominated at one low richness site); 2) Disturbance specialists - these had a higher frequency at sites of low richness (disturbed) sites and could achieve dominance at sites of low richness (with the exception of*Vulpia* spp. which also dominated at two high richness sites). Dominance was distributed over a number of taxa. Apart from the native grasses *Poa* spp. and *Themeda australis*, with 25 and 12 dominance records respectively, only *Plantago lanceolata* was dominant at more than 4 of the 60 sites.

Table 4. Ten most frequently recorded exotic taxa, distribution of their records over sites of high and low species richness and occurrence as dominant (>10% cover) or non-dominant components of the vegetation. Where more than one species is listed, the first-named is the most frequently occurring, although not all records could be separated. a = annual, p = perennial, g= grass, f = forb

Species/ species group	Low richness		High richness		Total records	Life history
	Dominant	Non-dominant	Dominant	Non-dominant		
Hypochoeris radicata/H. glabra	1	20	0	24	45	pf/af
Plantago lanceolata	5	20	0	7	32	pf
Vulpia bromoides/V. myuros/ V. muralis	2	11	2	5	20	ag
Trifolium arvense	1	9	0	8	18	af
Centaurium erythraea/C. tenuiflorum	0	7	0	11	18	af
Bromus racemosus/B. hordeaceus/ B. molliformis	2	12	0	3	17	ag
Trifolium repens	0	7	0	9	16	pf
Petrorhagia velutina	0	9	0	6	15	af
Paspalum dilatatum	1	10	0	3	14	pg
Conyza albida	0	7	0	6	13	pf

Without finer records of abundance, it is not possible to know the extent to which tolerant species might increase their cover at sites of low richness and thus contribute to reductions in total native richness. Previous analyses of the entire survey data set (7) showed a significant negative correlation both between numbers of native species and disturbances as well as between numbers of native species and numbers of exotic species (once the effects of disturbances were removed). Thus even non-dominant exotics may displace natives through their direct presence. Nonetheless, the data and observational evidence suggest that disturbance specialists may contribute even more to the reduction in rare species by increasing their cover in response to disturbance. Perennial exotic grasses are of particular significance in this regard; the six sites of lowest richness (native species <8) were all dominated by exotic perennial grasses, had high levels of soil disturbance and all had a litter layer >5 cm deep. Thus under conditions of disturbance, exotic perennial grasses may be capable of permanently displacing native species, while smaller-statured exotic forbs such a *Centaurium* spp. and *Petrorhagia velutina* may have only a minor competitive effect.

The following events and mechanisms are likely to operate in the process leading to loss of native species richness in herbaceous vegetation and are consistent with our observations:

a) some exotic species are able to invade natural vegetation without gross levels of exogenous disturbance;
b) physical disturbances destroy populations of native and exotic plants; disturbances encourage establishment and dominance by exotics, both newly-introduced and occurring at the site;
c) pre-emptive occupation of sites by exotics, reduces post-disturbance recolonization by natives which are often slower (lower seed production, slower growth rates);
d) site enrichment (nutrients, water) can lead to competitive exclusion of less responsive species (often native) by more responsive species (often exotic);
e) in the absence of further disturbance, perennial grasses may accumulate litter and suppress smaller statured interstitial species; this may occur in native communities dominated by perennial grasses in the absence of fire or intermittent grazing or mowing.

The effects of soil disturbance, enrichment, invasion by exotic perennial grasses followed by a period of low disturbance may lead to the greatest reduction in native species richness and be effectively permanent. It is suggested that in cases of unavoidable disturbance, selective control of exotic perennial grasses may be a useful strategy where limited resources are available for conservation management. Although more detailed observations are needed to fully describe the impacts of exotics on native richness, differential effects that relate to plant morphology are indicated by the data and by theory (2,3).

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ECOLOGY OF WOODY WEED INVASIONS IN THE TROPICAL WOODLANDS OF NORTH-EASTERN AUSTRALIA: IMPLICATIONS FOR MANAGEMENT

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Summary. Attempts at controlling exotic woody weed invasions in tropical woodlands of north-eastern Australia have generally revolved around reliance on the competitive ability of existing vegetation to suppress invading populations, and on the development of mechanical or chemical control methods for restoring invaded areas. However, there is very little experimental or observational evidence to support this approach. In this paper we review some of the pertinent literature and present some empirical evidence in support of an approach that focuses research and management efforts on limiting dispersal of invading plants and implementing more complex management regimes that are based on the negative effects of disturbance on invaders.

INTRODUCTION

Shrub invasion in grazed ecosystems is a common problem throughout the world. Abundant examples describe the conversion of open grasslands, savannas, and woodlands to shrublands and closed woodlands. As density and stature of invading shrubs increases, fewer ecosystem resources are available for herbaceous growth. Consequently, livestock carrying capacity is reduced, soil erosion is increased, and species, habitats, and ecosystems are endangered. Much consternation and economic expenditure has accompanied this phenomenon and yet the problem persists.

Most attempts at reversing this trend have revolved around some combination of mechanical, chemical, or biological control in heavily invaded areas. Although a substantial area is completely dominated by exotic shrubs and few landscapes are completely free of isolated individuals, the majority of land area remains open or occupied at relatively low densities. Unfortunately, few resources have been expended to examine proximate causes and mechanisms of invasions and the implications for management aimed at containing invasions and maintaining productivity. Causative factors must be altered if invasions are to be contained and mechanisms may provide clues to key processes that foretell invasions and allow appropriate actions. Any realistic examination of causes and mechanisms must include both the invading species and ecosystem attributes (12).

Ecosystem attributes. Tropical and subtropical woodlands represent about 92 mha of Australian rangeland (11). These ecosystems evolved with periodic extended drought (8) and large-scale intensive fires (4), but lacked exposure to heavy grazing by large herbivores (9). Consequently, bunchgrasses dominate the herbaceous layer. Although aboveground net primary productivity is relatively high compared to other grasslands, basal area is low (<3%). Therefore, even in undisturbed ecosystems where disturbance is low, much of the soil surface is unoccupied and available for colonization. Even moderate levels of disturbance decreases perennial bunchgrasses basal area (10), increasing openings where seeds of invading plants may establish.

Livestock grazing is by far the most extensive land use (11). Herbaceous production in the wet season typically exceeds grazier demand and intake during the dry season is limited by low digestibility (5). However, cattle numbers have approximately doubled in the past twenty years.

This increased forage demand and utilization has resulted in shifts in species composition in the herbaceous layer toward annual grasses and forbs (10). Increased availability of annual grasses and forbs has a positive feedback effect on livestock intake (1). In turn, increased intake and compositional shifts have a negative feedback on amounts of herbaceous growth available as fine fuel, reducing the frequency and intensity of fire. This disruption of the fire regime has resulted in a loss of equilibrium in the relationship between woody and herbaceous components of the vegetation (15) and allows for the greater expression of the woody component.

Invader attributes. Two of the most economically important woody weeds in the north-eastern woodlands are rubbervine *(Cryptostegia grandiflora)* and prickly acacia *(Acacia nilotica)*. Rubbervine was introduced in the late 1800s around population centres as a horticultural plant and is now common in the eastern part of the region (13). It commonly inhabits the more productive lowland areas adjacent to ephemeral and permanent watercourses. In addition to an ability to exist as a shrub, it can climb into the canopy of established trees. Seed production is very high (>>5K/ mature plant), seeds are viable (germination >90%) and dispersal is via wind or water. When established plants are subjected to top removal, they can resprout from below ground parts. Many naturally occurring stands are monocultures.

Prickly acacia is most common in the Mitchell grasslands, but is increasing rapidly throughout the east as well (13). It is a leguminous shrub or small tree and is capable of producing large quantities of viable seeds (>l0k/mature tree). Seed viability is high (>80%) and seed longevity may exceed 5 years in the soil. It was introduced originally as a fodder tree and seed dispersal via cattle is very effective. It can exist in near monocultural stands as well. In the western portions of it's geographic range, prickly acacia originally was concentrated near bore drains. Although large trees with high seed production remain concentrated in these well watered areas, populations have spread throughout entire paddocks where livestock have access. Recently, it has spread eastward into more mesic ecosystems, where seed producing trees are widely distributed across the landscape.

Possible causes and mechanisms. Historical and anecdotal reports as well as experimental evidence suggests that these woody plant increases are relatively recent (c. 25-40 y). Invasions are attributed to two general causes: 1) decreased competitive ability of current herbaceous vegetation assemblages or 2) decreased fire frequency and intensity. Although the two causes are related and interactive, it is important to separate and quantify each if strategies are to be devised that can limit Invasions.

If competition from herbaceous vegetation is to be a major factor limiting shrub survival, it is most likely during the seedling and juvenile stages of the life cycle. When seeds of invading shrubs are present on a site, germination and emergence are likely limited only by viability and moisture availability (6). These conditions are frequently met in north-eastern Australia, so germination and emergence are likely occurrences on most sites. Although woody plant growth may be limited if herbaceous plants are capable of pre-empting moisture, effect on survival is more critical in depressing population size and limiting invasions (2). If survival is unaffected and woody plants mature, the effect of the herbaceous layer in limiting survival, growth and reproduction is diminished (16). As shrubs mature, below ground investment in both extensive tap root systems and more finely divided shallow root systems insure shrub access to soil moisture and nutrients. Logically, life history relegates the role of herbaceous vegetation in limiting shrub populations to the seedling and juvenile stages. Thus, we initiated experiments to examine the ability of common, highly competitive perennial grasses to limit the success of juvenile shrub seedlings.

METHODS

To test the effect of herbaceous vegetation in limiting woody plant success, we introduced seed of rubbervine and prickly acacia into established vegetation dominated by perennial grasses and monitored survival. In a glasshouse, we introduced 15 seeds of each species into pots (50 cm in diameter x 25 cm deep) in which perennial grasses had been transplanted and grown for 90 d with supplementary water. The grasses were speargrass *(Heteropogon contortus)* or Indian couchgrass *(Bothriochloa pertusa)*. Speargrass is a native perennial bunchgrass that is indicative of light to moderate grazing (1). Indian couchgrass is a stoloniferous perennial grass introduced from India and is indicative of heavy grazing. Throughout the experiment the grasses were defoliated biweekly at one of three levels (heavily = 10 cm, moderately = 40 cm and undefoliated). Woody plant seedlings were not defoliated. Immediately after shrub seeds were introduced to the pots, all pots were watered to saturation for 4 d to simulate a germinating rainfall event. In addition, pots were well watered at three different intervals (5 d, 14 d, and 21 d) to simulate rainfall patterns typical of good, average and dry years, respectively. We monitored shrub seedling emergence and subsequent survival for 90 d.

In January 1992, we introduced seeds of rubbervine and prickly acacia into 1 m^2 plots dominated by perennial grasses that had been protected from grazing for >20 y. Although the wet seasons of 1991-1992 and 1992-1993 were among the driest on record, seed germinated in some of the plots and was monitored over the next two years.

RESULTS AND DISCUSSION

In the glasshouse study none of the treatments significantly affected seedling survival. Seedling survival for both species exceeded 95% for both species regardless of competing species, defoliation regime, or watering regime. In the field study, prickly acacia survival was 62% and rubbervine survival was 87% after two seasons. Although these experiments represent a limited range of conditions and a short time period, the combination of our results and research and observations from around the world in similar situations leads us to suggest that the likelihood of limiting shrub invasion of open woodlands via the competitive effects of the herbaceous layer is very low. This conclusion, then, focuses attention on the alternative hypothesis presented above; that the primary value of herbaceous vegetation in limiting shrub invasion is as fine fuel to initiate fires of sufficient intensity and frequency to limit woody plant success.

An understanding of the attributes of the invading species indicates seed availability and viability seldom are limiting factors if mature plants are within dispersal distance. Herbaceous vegetation may limit seedling survival under some conditions (7), but if essential resources (notably moisture) are in adequate supply, the effect is greatly diminished. If shrub seedlings survive to the juvenile stage, it is highly unlikely that herbaceous vegetation can reduce survival. During this phase, herbaceous vegetation may have more value as fine fuel to increase frequency and intensity of fires than for exploitative or interference competition. Although most woody shrubs are fire tolerant, frequent hot fires may remove top growth and greatly limit their ability to compete for water and nutrients in upper soil profiles (14). If this is the case, juvenile woody plant effects on herbaceous production can be greatly limited. In addition, repetitive top removal can effectively maintain populations of woody plants as juveniles and greatly depress seed rain on a site. By limiting seed production at the population level, presence of woody plant seeds in the seedbank would eventually run down if treated areas are sufficiently distant from seed producing trees.

However, if woody plants survive to become adults, herbaceous vegetation has little effect on either survival, growth or reproductive success (3). Spot treatment with chemical, mechanical or attempts to control populations via biological controls inevitably leave seed producing adults capable of restocking the seed bank. Thus, there remains the potential for rapid increases in invasive shrub populations.

Based on our observations and literature interpretations, we suggest it is futile to expect that herbaceous vegetation, however well managed, can have more than minimal impact on the rate of shrub invasions in tropical woodlands. Research and extension efforts could more effectively be directed toward developing cost-effective management schemes that focus on the judicious use of fine fuel for fires that can check the increase in shrub density and stature.

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ECONOMICS OF CHANGING ROTATIONS TO COMBAT HERBICIDE RESISTANCE

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Summary. The economics of altering rotations to delay the development of resistance to herbicides was investigated using a whole-farm, bioeconomic model called MIDAS. The model represents the dryland farming system in the eastern wheatbelt of Western Australia. The profitability of various cereal-pasture-lupin rotations was compared to those currently optimal in the farming system. The effect of wool and wheat prices and length of pasture phase on the profitability of the rotations was examined. Using prices expected in the medium term, altering rotations by the inclusion of pasture into cereal-lupin rotations had a significant adverse effect on farm profit. The extent of profit decline was sensitive to soil type and product prices.

INTRODUCTION

Use of Integrated Weed Management (IWM) has been widely promoted as the key to managing herbicide resistant weeds. A key element of IWM is the inclusion of pasture phases in the rotation, since this allows the use of a wider range of non-selective weed control measures, especially knockdown herbicides and grazing. However the decision to change rotation is very complex and is influenced by many factors other than herbicide resistance. These include prices, production costs, soil type, availability of adapted legume species, yields, crop disease, nitrogen fixation, machinery size, farm debt, and attitudes to risk

Because it is such a complex issue, it is not clear that it is in the best interests of farmers to change rotation before resistant weeds build up to high densities. In this paper we examine the short- to medium-term economic effects of changing rotations to delay build-up of resistance. We use a whole-farm, bioeconomic model (called MIDAS) which incorporates the main factors influencing rotation choice other than herbicide resistance. The model is used to investigate (a) the change in short-run profit resulting from the inclusion of pasture into continuous cropping rotations, (b) profitability of different lengths of the pasture phase and (c) the sensitivity of results to pasture yields and grain and wool prices.

METHODS

Model description. MIDAS is a mathematical programming model which represents a typical farm in the eastern wheatbelt of Western Australia, about 270 km east of Perth. Average rainfall is 310 mm per annum and the main products are wheat and wool. A proportion of cropping is done continuously, usually in a wheat-lupin rotation, with one or two years of wheat after the lupin crop.

The model calculates the combination of farm enterprises, rotations, sheep flock size and structure, machinery usage and sheep feeding strategies which maximises farm profit in the medium term. The model output gives details not only about the most profitable set of activities but also the profitability of activities not selected. A detailed description of the model can be found in Kingwell and Pannell (1) and Morrison and Young (2). Model data and assumptions are presented by Pannell and Bathgate (3). Only a brief overview of the model is given here.

Seven soil types are described in the model, and they are classified according to their production characteristics. Up to 20 rotations per soil type are represented in detail with allowance made for the effects of current crops and pastures on subsequent production. This is due to factors such as disease break effects, stubble for grazing, nitrogen fixation and the reduction in pasture production after crop. The impact of these factors is quantified for each rotation option on each soil type.

Analysis of rotations. The model was modified on three soil types by the introduction of pasture into the cereal-lupin rotations. The soil classes on which these novel rotations were introduced are those lighter textured soils better suited to cereal-lupin cropping. These are soil types S2 (sandplain), S3 (gravelly sand) and S4 (duplex) (3).

The new rotations were chosen in consultation with general advisors of the Department of Agriculture. For each phase of each rotation, we obtained estimates of production parameters and factors such as nitrogen fixation, soil structure effects, etc. Most of the data for these rotations had to be estimated subjectively (in collaboration with advisors) due to lack of experience with the rotations. The model was run to compare profitability of the new rotations with traditional rotations. We also tested the impact of different combinations of wheat and wool prices on the relative profitability of rotations. Finally, different levels of pasture growth were examined on one of the soil types to determine what effect it has the profitability of the rotations.

RESULTS AND DISCUSSION

Table 1 shows how much the profitability of the new rotations would have to improve for them to be as profitable as continuous cropping with wheat and lupins. These values are termed "shadow costs" and they are based on average returns per hectare over the length of the rotation. They do not directly allow for impacts of the rotation on herbicide resistance.

Table 1. Shadow costs of wheat-pasture-lupin rotations

Soil type:	S2	S3	S4
Rotation*	($/ha)	($/ha)	($/ha)
CPPPLCL	11.7	7.3	14.8
CPPCL	11.2	8.9	14.8
CPL	18.9	17.1	24.1

* C = cereal crop, L = lupin crop, P = pasture.

On each of the three soil types examined, CPPPLCL performs similar economically to CPPCL. The advantage which the longer pasture phase has in allowing a more thorough run-down of the ryegrass seed bank means that it is likely to be preferred from the point of view of resistance management. Thus when resistance management is considered (in addition to the many factors already considered in calculating Table 1), CPPPLCL is likely to be the best economic performer of these three rotations. Even though it is the best of the rotations we considered, CPPPLCL requires farmers to make a substantial sacrifice of short-run income compared to CL or CCL.

Given the low profit margins in the eastern wheatbelt region the decreases in profit shown in Table 1 are substantial. It seems unlikely that farmers will be prepared to introduce pasture into continuous cropping rotations unless resistance is imminent. From a long-term economic point of view, continuing to crop may well be the best decision for them to make. This is reinforced by current evidence that the number of selective herbicide applications needed to produce a herbicide resistant ryegrass population is not reduced by inclusion of a pasture phase in the rotation. Once resistance becomes a problem one of the new rotations may be adopted. Possibly, then, the best way to view the values in Table 1 is as the decline in profit which will occur after resistance has become established in the ryegrass population and the farmer has been forced to change rotation.

It is notable that on each soil type, CPL is the least profitable of the rotations we considered. This is due to the low pasture density in this rotation and to the higher cost of herbicides required to control ryegrass in the pasture prior to the lupin crop.

Effect of changing prices. The results in Table 1 are for a particular set of assumptions. It may be that different assumptions would lead to different conclusions. To investigate this possibility, we solved the model for a wide range of wheat and wool prices. The results of this exercise varied for different rotations on different soil types. An illustrative set of results for the CPPCL rotation on soil type S2 is shown in Table 2.

Table 2. Shadow prices of CPPCL rotation on soil type S2.

Wheat price ($/T n.p.r)	Wool price(c/kg greasy)			
	250	300	350	400
130	8.6	10.6	9.8	8.2
170	12.2	11.2	9.9	9.0
210	17.3	16.6	16.7	15.3

Naturally, the higher the wool price, the more profitable it is to include pasture in the rotation. Conversely, the higher the wheat price, the greater is the profit advantage of cropping. These trends are evident in Table 2 but even at the highest wool price and lowest wheat price, the CPPCL rotation is still an average of $8.20 less profitable than CL.

For the other soil types, results not presented here show that these cereal-pasture-lupin rotations can compete economically with cereal-lupins in certain circumstances. In particular if wool price is 350c/kg greasy, and the wheat price drops to $150/tonne (soil type S3) or $130/tonne (soil type S4), there is no economic advantage of CL over CPPCL or CPPPLCL even in the short term. It is anticipated that for the foreseeable future, wheat prices will remain above these levels. If the wool price is less than 350c (as it currently is), the wheat price would have to fall even further for it to be profitable in the short term to change to CPPPLCL or CPPCL.

Effect of increasing pasture growth. Apart from higher wool prices an alternative way of improving the profitability of cereal-pasture-lupin rotations is to increase pasture production. Low pasture density after cropping is a primary contributor to the relatively low profitability of cereal-pasture-lupin rotations. There are various means by which pasture production may be improved, including plant breeding, grazing management and re-seeding. Here we are not specific about the source of extra pasture production but consider hypothetical increases of 10 percent and 20 percent above current levels. Results for soil type 3 are shown in Table 3.

Prospects for these novel rotations appear best on soil type 3. Even so a 20 percent increase in pasture production on this soil type is not sufficient to make them as profitable in the short term as CCL. However the best of them (CPPPLCL) is only $2.00 per hectare per year behind CCL. It would be expected that the advantages of this rotation for resistance management would more than compensate for this small sacrifice of short-term income.

Table 3. Shadow costs of wheat-pasture-lupin rotations on soil type S3

Increase in pasture growth:	0%	10%	20%
Rotation	($/ha)	($/ha)	($/ha)
CPPPLCL	7.3	3.2	2.0
CPPCL	8.9	5.9	4.8
CPL	17.1	16.5	16.0

CONCLUDING COMMENTS

The results presented here are, of course, specific to a particular region with its own production system and production levels. Even within this region we have shown that results of adopting a new rotation are very sensitive to factors such as wheat price and wool price. Nevertheless the study has highlighted some important lessons of broader relevance.

The introduction of a pasture phase into continuous cropping rotations to delay the onset of resistance can be very costly. As unpalatable as it appears, it may be in farmers' best interests to wait for resistance to develop before responding with a new rotation, especially given wheat and wool prices expected to prevail over the next 3 to 5 years.

The profitability of altering rotations is very dependant on soil type and product price. Introducing pasture is only likely to be a viable strategy for delaying resistance on soils where the profitability of pasture is similar to that of crop. On other soils, it may be better to wait for resistance to appear before moving to adopt the rotations examined here.

Note, however, that we have not yet identified how much short-term income it is worth sacrificing in order to delay resistance, so a cautious interpretation of our results is necessary. Also note that the results do not imply anything about the costs of other management responses, such as cultivation, burning or seed catching.

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ECONOMIC INTEGRATION OF CHEMICAL AND NON-CHEMICAL WEED CONTROL UNDER HERBICIDE RESISTANCE IN CONTINUOUS CROPPING

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Summary. Even under threat of herbicide resistance, inclusion of pasture into continuous cropping systems will not be acceptable or even advisable in all situations. However there is a range of other non-chemical control options available, including cultivation, burning and choice of wheat cultivar. In this study we investigate the optimal combination of chemical and non-chemical control of ryegrass under threat of herbicide resistance. Our model is a dynamic non-linear programming model representing a continuous cropping system infested with ryegrass in Western Australia. We investigate the impact which herbicide resistance has on the optimal combination of chemical and non-chemical control and estimate the cost of failing to respond optimally to the threat of resistance.

INTRODUCTION

There have been a number of studies of the economics of pesticide resistance in insects and diseases (2) but almost no research on the economics of herbicide resistance. In this paper we address the economics of herbicide resistant weeds in Western Australian dryland agriculture, a mixed farming system producing livestock and various crops. Our focus is on the management of herbicide resistance before it reaches high levels rather than on responses to a high existing level of herbicide resistance.

By far the greatest number of occurrences of herbicide resistance in Australia has been for annual ryegrass (*Lolium rigidum*) growing as a weed in continuous cropping rotations (usually wheat/lupins) treated with selective grass herbicides (1,5). This reflects the frequency with which selective herbicides are usually used in continuous cropping. This system is the focus for our study.

The Management Options. Resistance develops after a number of years of chemical use, whereas costs of the various management responses are incurred in the preceding years. Evaluating management strategies to prevent herbicide resistance requires comparison of costs and returns incurred over time. Discounting both future costs and future benefits is a method used to determine the "net present value" of a strategy. A strategy with the highest net present value is most beneficial to the farmer.

Of the many strategies proposed for prevention of herbicide resistance two strategies are evaluated in this paper The first strategy is the use of a non-chemical weed control method, such as mechanical cultivation. The second strategy is the application of lower dosages of the herbicide. Our case study is for a situation where continuous cropping is the most profitable land use prior to development of herbicide resistance.

The cost of non-chemical control varies for different methods. In the case of mechanical cultivation there are the costs of machinery usage as well as potential costs from soil erosion and a reduction in crop yields if planting must be delayed to allow cultivation. The benefits of this strategy are that the weed population can be controlled without applying selective pressure for weeds that are resistant to selective herbicides. The strategy of reducing herbicide dosage has the benefit of lower chemical costs, less phytotoxic damage to the crop and reduced selective pressure for resistant weeds. The costs of this strategy are reduced weed control and therefore lower crop yields in the short run and greater weed seed numbers the following year. Since the choice of one strategy (i.e. cultivation or reduced herbicide rates) affects the profitability of the other, it is necessary to take an integrated approach to select the appropriate combination of the two strategies.

Model description. We model the build-up of resistance to diclofop-methyl by annual ryegrass (*Lolium rigidum*) in wheat crops in Western Australia. The model is implemented as an annual time-step simulation in a microcomputer spreadsheet. Statistical estimation methods, data sources and specific functions used are not presented here. This information is available from the authors. The model draws on that developed by Maxwell *et al.* (3) but parameters and several of the functions are specific to Australian conditions.

The model includes the following functions:

1. Density of susceptible weeds surviving herbicide application as a function of herbicide dose and pre-treatment weed density.
2. Proportional phytotoxic damage to the wheat crop as a function of herbicide dose.
3. Wheat yield loss from competition with both susceptible and resistant weeds.
4. Autonomous natural mortality of weed seeds over summer.
5. Weed mortality from non-chemical control.
6. Carry-over of weed seeds (susceptible and resistant) from one season to the next.
7. Seed production per weed as a function of intra- and inter-specific competition.

Parameter values assumed for the analysis were as follows:

Initial density of susceptible weeds:	100/square m;
Initial frequency of resistant weeds:	0.000001;
Weed-free wheat yield:	600 kg/ha;
Price of wheat:	$120/tonne;
Price of herbicide:	$55/kg a.i.;
Other costs of crop production:	$89/ha;
Cost of extra cultivation for weed control including indirect costs such as soil degradation and erosion:	$10/ha;
Gross margin of grazing sheep:	$25/ha.

Due to the variation in effectiveness and costs of non-chemical weed control we look at three different levels of effectiveness, where cultivation kills either 25%, 50% or 75% of all weeds. For convenience, mechanical cultivation will be assumed to be the non-chemical weed control method in this paper. Cultivation is a typical non-chemical weed control method which farmers in Western Australia use in conjunction with chemical weed control. For simplicity we assume that the land is cropped with wheat each year until the number of weeds resistant to herbicide is so great that livestock grazing of pasture is more profitable than further cropping. We also assume that weeds other than ryegrass are well controlled.

RESULTS AND DISCUSSION

We calculated the net present values of 12 different management scenarios representing different combinations of chemical and non-chemical weed control (Table 1). The three herbicide dosages in Table 1 correspond to 50 percent, 75 percent and 100 percent of the label recommended rate for control of ryegrass with dichlofop-methyl. These herbicide dosages are consistent with current farmer practices in Western Australia. Four different levels of effectiveness of cultivation are considered: Zero, 25 percent, 50 percent and 75 percent weed mortality. Thus the first line of results is for a strategy relying totally on herbicide for weed control. The other three lines are for strategies which include non-chemical control.

Table 1. Net present value of agricultual production (A$/ha over 30 years at 5 percent real discount rate)

Weeds killed by cultivation (%)	Herbicide dosage (kg active ingredient/ha)		
	0.188	0.281	0.375
0	496	660	686
25	540	685	666
50	703	778	726
75	1058	975	886

If no cultivation is used lowering the herbicide rate below 0.375 kg/ha reduces farm profitability (Table 1). However a cultivation which kills as few as 25 percent of the weeds makes it profitable to reduce the herbicide dose by 25 percent. If cultivation can be 75 percent effective at controlling weeds, it would be profitable to cut herbicide dosage by 50 percent. Thus the lower herbicide dosages shown in Table 1 can be considered when at least 25 percent of weeds have been killed by other means such as cultivation. A lower weed density following cultivation means that the yield loss prevented by applying herbicide is lower, so that the highest rate of herbicide is not warranted. Pannell (4) showed that the optimal herbicide dose is positively related to weed density, so a lower density prior to spraying is associated with a lower optimal herbicide dose.

Table 2. The number of years of crop before pasture becomes a more profitable land use

Weeds killed by cultivation (%)	Herbicide dosage (kg active ingredient/ha)		
	0.188	0.281	0.375
0	3	7	7
25	4	9	7
50	9	9	9
75	16	16	16

Table 2 shows the number of years of crop which can be grown before the density of weeds reaches a level at which crop is less profitable than pasture. Pasture is assumed to be $88/ha less profitable than a weed-free crop. At the lowest dosage of herbicide and zero to 25 percent effectiveness for cultivation the population of non-resistant weeds very quickly builds up to such high densities that cropping is less profitable than pasture.

Table 3 shows that if the lowest herbicide dose is used and cultivation achieves a weed kill of 50 percent or less, then at the time when cropping is abandoned, the proportion of weeds which are resistant to herbicide is still very low. At the higher herbicide dosages, susceptible weeds are contained, but eventually selection pressure precipitates the onset of resistance. If the farmer relies solely on rate cutting to delay the build-up of resistance, herbicide dosage has to be reduced so much that the population of susceptible weeds increases to the point where crop yields are decreased substantially.

Table 3. The proportion of herbicide-resistant weeds present after the cropping phase indicated in Table 2.

Weeds killed by cultivation (%)	Herbicide dosage (kg active ingredient/ha)		
	0.188	0.281	0.375
0	0.00006	0.54	0.98
25	0.0002	0.53	0.99
50	0.15	0.98	1.0
75	1.0	1.0	1.0

Effectiveness of cultivation is the main determinant of years of cropping before resistant weed density reaches a critical level. Herbicide dosage affects the net present value but does not substantially affect the time to resistance build-up. This result depends on the simple genetic assumptions implicit in our model and does need some empirical verification. Results of this study show that it is not sufficient to consider individual control strategies without examining their interaction. Furthermore the evaluation of the impact of control measures on resistant weeds should account for the population of susceptible weeds.

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THE ECO-ECONOMIC THRESHOLD PERIOD FOR CONTROLLING BARNYARD GRASS IN SUMMER SOYBEANS

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Summary. A term of "Eco-economic Threshold Period for Weed Control" was proposed and field experiments were conducted in the Beijing region of China to study the functional relationship between the summer soybeans (*Glycine max.* L.) yield and the relative weedy and weed free days by barnyard grass (*Echinochloa crus-galli* (L.) Beauv.). Models for calculating the eco-economic threshold period for the weed control in the crop were then developed. Results calculated using these models showed that the eco-economic threshold period for controlling barnyard grass in summer soybeans was 16.8-26.0% days of the total crop growth season after emergence. This is the critical period for avoiding the weed damage whilst maximizing the use of the weed in reducing soil erosion and the loss of light interception and soil nutrients caused by insufficient plant covering during the early growth phase.

INTRODUCTION

Weeds not only have harmful aspects on crop productivity but also useful in the agro-ecosystem in preventing soil erosion (2-7). Therefore, the principle of weed control should be to avoid their negative effects, utilize their positive effects and optimize the socio-economic ecosystems (4).

Soybeans are usually sown in row spacings of more than 45 cm. Their vegetative growth and increase in leaf area develop slowly in the beginning of the growth season so that most parts of the field are bare for a long period after planting. As a result, the soil erosion and the loss of light interception without weed mulching in the field during this period is quite heavy, especially in sloping fields. Early chemical weed control will not only aggravate this situation but also may increase the environmental pollution and the cost of weed control.

The objectives of this work were to develop models for calculating the eco-economic threshold period which might serve as a guide for efficiently controlling barnyard grass in summer soybeans.

METHODS

Experiments were conducted in three fields with a large natural seed bank of barnyard grass in the Beijing region during 1984 and 1985. Soybeans was seeded in 7x45 cm row spacing to give a final density of 21 plants/m^2 in 1984 and in 6x45 cm row spacing to give a final density of 24 plants/m^2 in 1985. After seeding the fields were immediately irrigated to improve the emergence of the weed and crop. The plot size of each experiment was 12-15 m^2 containing 6 rows of soybeans. All weeds except barnyard grass in the experimental plots were removed during soybean growth season by hand weeding. All treatments were accomplished with 3 replications.

In 1984, barnyard grasses were allowed to emerge together with soybean and grow for 0, 21, 42, 63, and 84 days after crop emergence and for the entire growth season at the density of 6.7, 33, 73, and 147 barnyard grass plants/m^2, while for 0, 14, 28, 38, and 42 days and for the entire growth season at the density of 6.7, 33, 73, and 147 plants/m^2 in 1985. After the termination of each weedy duration these plots were then kept weed free by hand weeding until soybean maturity. In an other experiment in 1985, plots were kept weed free for 0, 21, 35, 49, 63, and 77 days after soybean emergence and for the entire season. After the terminating of the weed free duration barnyard grasses were allowed to emerge and grow until soybean maturity.

The eco-economic threshold period for weed control in this paper was defined as "A weed free period which can economically and ecologically avoid the damage caused by the growth of weeds emerging before and during crop growth season". The onset of the threshold period was defined as the maximal percent weedy days after crop emergence before the crop relative yield was over 97% of the weed free treatment. The end of the threshold period was defined as the percentage of the least weed free days after crop emergence after which the growth of the emerging weeds did not reduce crop yield by more than 3%.

The functional relationships between soybean relative yield and the relative weedy and weed free days after crop emergence were fitted by means of computer software PlotIT.

RESULTS AND DISCUSSION

1. Relationship between weedy days and soybean yield. As shown in Table 1, barnyard grass irrespective of plant density did not significantly reduce soybean yield when the relative weedy duration was kept within the first 23.9% days of the total crop growth season after emergence in 1984. However the relative weedy days by barnyard grass lasting longer than 47.7% days of the total crop growth season after emergence decreased the soybean relative yield significantly and reached the maximum after the first 95% relative days. There was a significant interaction effect between weed density and weedy duration on soybean yield. Soybean relative yield was reduced as increase of weed density and the lasting of the weedy duration. In 1985, barnyard grass interference resulted a less reduction in soybean yield and a delayed damage time because of its reduced density in this year (Table 2). The function fitting results indicated that there was a Weibull functional relationship with r= 0.98 shown as follows between the relative weedy duration (X_u) by barnyard grass at the highest interference density and the relative yield of soybean (Y_u) :

$$Y_u = 107.6(1\text{-}\exp(-(1.00376-0.000074X_u)^{334.1})$$ <1>

2. Relationship between weed free days and soybean yield. In 1985, only those barnyard grass which emerged together with soybean and was in interference with soybean for an entire growth season caused a significant reduction in soybean yield. However it did not reduce soybean yield when it emerged 21 days after soybean emergence or later because it hardly emerged and formed little biomass under strongly shading of soybean (Table 3). The function fitting results showed that there was a positioned exponential functional relationship with r= 0.99 shown as follows between the relative weedy free days of barnyard grass after crop emergence (X_d) and the soybean relative yield (Y_d):

$$Y_d = -63.4\exp(-0.1172X_d)+100.02$$ <2>

3. Establishment of models for calculating the eco-economic threshold period. According to the definition of the eco-economic threshold period for weed control and the above functions <1> and <2>, the functional relationships between the relative weedy and weed free days by barnyard grass and the soybean relative yield was fitted. The following models were derived:

$$X_u= 16.8\%T$$ <3>

$$X_d= 26.0\%T$$ <4>

where,

T= total crop growth days after emergence

X_u= onset of the eco-economic threshold period in percent days of the total crop growth season after emergence

X_d= end of the eco-economic threshold period in percent days of the total crop growth season after emergence

Table 1. Weedy duration by barnyard grass in relation to soybean yield in 1984

Weedy day after emergence		Density plants/m²	DM g/m²	Relative height x DM g/m²	Soybean relative yield %
days	%				
0	0.0	0.0	0.0	0.0	100.0
21	23.9	6.6	1.7	1.6	100.0
		33.0	7.0	6.5	100.0
		73.0	13.1	14.2	99.9
		147.0	23.5	32.0	97.8
42	47.7	6.7	15.3	24.3	99.9
		33.0	53.5	68.5	81.0
		73.0	99.6	116.9	75.3
		147.0	176.9	210.3	62.0
63	71.6	6.7	22.9	53.9	99.9
		33.0	103.2	192.0	68.9
		73.0	150.4	299.0	63.1
		147.0	240.6	462.0	42.3
84	95.5	6.7	38.4	82.9	89.7
		33.0	120.3	252.0	64.1
		73.0	165.5	363.0	52.6
		147.0	289.0	578.0	34.1
88	100.0	6.7	37.9	80.9	89.7
		33.0	115.9	247.0	63.5
(Entire season)		73.0	146.8	327.0	51.0
		147.0	276.4	555.0	33.5

By combining the model of <3> and <4> it can be seen that the eco-economic threshold period for controlling barnyard grass in summer soybeans lay in the first 16.8-26.0% days of the total crop growth season after emergence, namely around 14 to 22 days after soybean emergence in the Beijing region.

The boundaries of the "critical periods for weed control" in many studies were usually arbitrarily defined as the period during which the relative crop yield exceeds 95% (1,8). But in our study they were defined as the period during which keeping weed free can ensure the crop relative yield exceeds 97% of the weed free treatment. This is because in our other research it was found that the loss caused by weed growth from soybean emergence to crop maturity could be usually counteracted by the value provided by it in preventing soil and nutrients from washing away and providing the soil with organic matter (4,5 Table 1-3).

Table 2. Weedy duration by barnyard grass in relation to soybean yield in 1985

Weedy day after emergence		Density plants/m²	DM g/m²	Relative height x DM g/m²	Soybean relative yield %
days	%				
0	0.0	0.0	0.0	0.0	100.0
14	16.5	3.3			102.9
		6.7			107.7
		20.2			108.1
		33.7			107.9
28	32.9	3.3	4.2	5.4	107.6
		6.7	14.5	22.3	100.5
		20.2	60.9	100.1	88.5
		33.7	94.9	156.4	86.1
35	41.2	3.3	14.5	23.1	100.5
		6.7	32.2	46.3	90.9
		20.2	89.5	148.5	86.2
		33.7	311.2	554.0	79.0
42	49.4	3.3	38.6	69.6	95.7
		6.7	77.3	133.7	84.7
		20.2	196.5	327.9	79.9
		33.7	324.2	560.4	75.1
85	100.0	3.3	54.8	124.4	90.9
		6.7	124.0	220.9	79.9
		20.2	227.8	432.0	78.5
		33.7	356.4	608.3	76.6

Table 3. Weed free and emerging period by barnyard grass in relation to soybean yield in 1985

Weed free days after emergence		Density plants/m²	DM g/m²	Relative height x DM g/m²	Soybean relative yield %
days	%				
0	0.0	303	775.8	1081.0	36.3
21	24.7	22	9.3	4.5	98.6
35	41.2	18	11.1	6.4	99.7
49	57.6	15	4.5	2.5	100.0
63	74.1	12	3.9	1.0	99.3
77	90.6	3	0.6	0.0	99.5
85	100.0	0	0.0	0.0	100.0

You has simulated the nitrogen loss caused by leaching in soybeans under weedy and weed free conditions and found that the nitrogen loss caused by leaching in soybeans without weed growth was more heavy than that with weed growth during the first 17% days of the total growth season because of the little vegetative growth and the limited uptake of nitrogen from soil by soybean plants (5). Results obtained in this study showed that barnyard grass emerging after the first 24.7% days or later in soybean growth season no longer significantly reduced the yield of summer soybeans (Table 3). These results indicated that this kind of weed growth had used only those resources which soybean could not use. According to the definition of the eco-economic threshold period and the results shown in Table 1, 2 and 3 it can be seen further that keeping barnyard grass free in soybeans after the end of the threshold control period by weeding will only waste money, while killing the weed emerging together with soybean immediately after its emergence can surely avoid the potential weed damage in the late growth season, but it will be not favourable for utilizing the positive aspects of the weed. Only keeping weed free within the eco-economic threshold control period can, in one side, avoid all the weed interference damage to the crop during the whole growth season, and, in other side, fully utilize the positive aspects of weed growth in the field ecosystem and achieve a highest eco-economic benefit in weed control.

Weed density reaches only half of its maximum before the first 16.5% relative days while it does after the first 24.7% days (5). This is just the time within the eco-economic threshold period for controlling barnyard grass. Weed control with post-emergence herbicides to keep the weed free within the threshold control period can also avoid the shortcomings of less chemical control percentage with pre-emergence herbicides because of weed emerging afterwards.

Nowadays, barnyard grass control in summer soybeans in China is usually blindly accomplished outside its eco-economic threshold control period. Usually 1-2 times of pre-emergence herbicides applications and 1 to 3 times of mechanically weeding are normally needed to avoid the weed damage to soybeans. This weed control performance usually results a weed control cost as high as 85 to 150 yuan/ha. However, when barnyard grass is kept free subjectively only within its threshold control period found in this study weed control cost will be reduced to 51 to 58 yuan/ha which saves over 40% of the conventional weed control cost. This is achieved by applying post-emergence herbicides such as sethoxydim, fluazifop (methyl, butyl or p-butyl ester), or imazethapyr at the time around the first 16% days of the total soybean growth season (the onset of its threshold control period) and its efficacy is kept until to the first 26% days after emergence (the end of its threshold control period.

By comparing world research results in weed-crop competition (1), Heemst found that the "critical period for weed control" in soybeans averagely arranged in the first 12-30% days of the total soybean growth season worldwide, which is similar to the eco-economic threshold period for controlling barnyard grass by the first 16.8-26% days found in this research. This implies that using the relative weedy and weed free time and the relative crop yield to present the functional relationship between weed interference duration and crop yield reduction can estimate the effect of weed species, crop varieties, and environmental factors on the threshold period for weed control. Therefore, the eco-economic threshold period for controlling barnyard grass in spring soybeans in China may be similar to that in summer soybeans found in this study. This is to be studied in the future.

Moreover, the results achieved in this study means also that the herbicide efficacy for controlling barnyard grass inn summer soybeans should remain at least from the application day till to the first 26% days of the total crop growth season and for the post-emergence herbicides their eco-economical application date would be around the first 16% days.

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OROBANCHE BROOMRAPES - STATUS AND POTENTIAL IN AUSTRALIA

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Summary. Broomrapes, *Orobanche* spp., are major weeds of broadleaf crops in the Old World, but the three species established in Australia are not yet important weeds here. Four species, crenate broomrape, *O. crenata* Forsk., Egyptian broomrape, *O. aegyptiaca* Pers., branched broomrape, *O. ramosa* L., and nodding broomrape, *O. cernua* Loefl. are potentially major agricultural weeds in Australia. A program to eradicate branched broomrape began in South Australia in 1992. The key is early identification of broomrape infestations and exhausting seed reserves by stimulating germination using host plants, prior to herbicide treatment.

INTRODUCTION

The parasitic broomrapes are major weeds of broadleaf crops in the Mediterranean, Europe and Asia, however despite warnings 30 years ago (3,7,21) broomrapes are not important weeds in Australia (5). Crenate broomrape, Egyptian broomrape, branched broomrape, and nodding broomrape are internationally important in a range of broadleaf crops (8). The comprehensive review by Foy, Jain and Jacobsohn (8) provides a background to the control and biology of broomrapes.

With the increase in field grown tomatoes and grain legume production in southern Australia over the past 20 years, it is surprising that broomrapes have not established as major weeds as they have in the northern hemisphere.

Australia remains almost free of broomrape. Until 1992, only the native Australian broomrape *O. cernua* Loefl. var. *australiana* (F. Muell ex Tate) J. Black ex G.Beck, and the introduced clover or small broomrape, *O. minor* Smith, occurred in Australia (6). The commercially important species, branched broomrape is now established in Australia near Murray Bridge, SA (W. Barker and M. Hyde, pers. comm. 1992). This was not the first time branched broomrape occurred in Australia. In 1911 it was collected in the sandhills near Glenelg in South Australia, however this population has not survived (6).

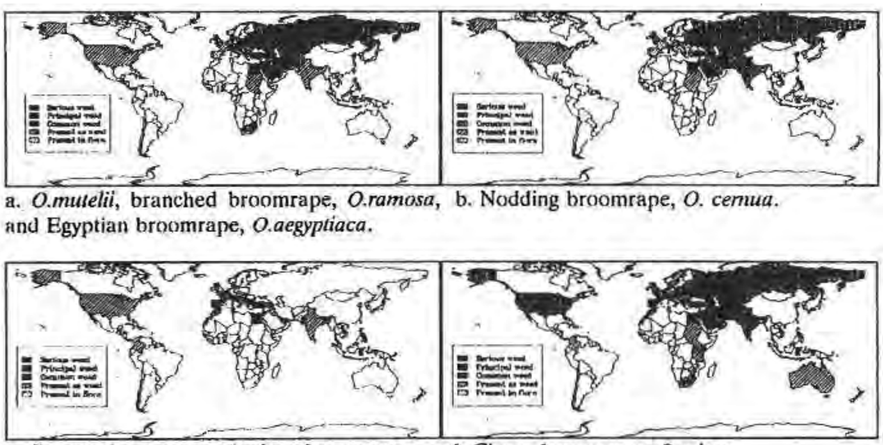
The recent discovery near Murray Bridge appears to be a new introduction. It is separated by 70 km and 82 years from the previous record, however the disappearance of the former infestation suggests that branched broomrape may not become a problem in Australia.

With this paper I hope to restart the discussion as to why broomrapes have not become a problem in Austalian agriculture and suggest ways to ensure the status quo continues.

DISCUSSION

Impact of broomrapes. Crenate broomrape dramatically reduces yield in peas and lentils (4) and faba bean (15) crops in Spain and is responsible for reducing grain legume plantings as farmers extend rotations to avoid parasitisation. Some crops in Morocco (1) and Spain (15) are totally destroyed. In Spain yield of faba bean was halved due to as few as four emerged crenate broomrape plants (14). Even vetch is affected and hay made un-marketable due to contamination (8).

Branched broomrape is a recurring problem in tomato production in California (16) and Greece (12) and tomato and potatoes in Lebanon (2). Tomato yield losses of 30 to 75% are reported from California and Hungary respectively (8). Both crenate and Egyptian broomrape reduce carrot yield and quality (19), and branched and Egyptian broomrape both affect tomato fields (17) in Israel.



a. *O.mutelii*, branched broomrape, *O.ramosa*, and Egyptian broomrape, *O.aegyptiaca*.

b. Nodding broomrape, *O. cernua*.

c. Crenate broomrape, *Orobanche crenata*.

d. Clover broomrape, *O.minor*.

Figure 1. Distribution of the four major weedy broomrape species by countries (2,4,9,12,15,17,19).

Nodding broomrape reduces tobacco leaf by up to 52% in India and attacks sunflowers in eastern Europe, Russia and the Middle East (13).

Australian broomrape by contrast is a rarely problem in subterranean clovers in Western Australia (3).

Figure 1 shows the geographical distribution of the broomrape species with a major impact on agriculture.

Biology and control. Broomrapes damage hosts by using there nutrients especially sugar. Broomrapes reduce quality of carrots, drawing on sugars from the roots (19). Tomatoes and eggplant have less fruit, and faba beans have reduced seed yield (16).

Broomrapes have tubers which store starch (20). Often the host dies, while the parasite is able to produce large amounts of seed using starch from the tuber (16).

Once broomrape is established, control is difficult. Fumigation with methyl-bromide, low doses of glyphosate and soil solarisation are all used with varying success (8). The false host plants such as flax reduce soil seed pools (Westbrooks, pers. comm. 1993).

Weed status

An average broomrape plant produce over one hundred thousand small seeds (2). The seed remains viable for at least 10 years and possibly up to 20 years in the soil and germination is stimulated by moist preconditioning and stimulation from host plant root exudates. Only seeds close to host plant roots germinate. Other seed remains dormant and viable. It is not affected by pre-emergent herbicides, and cultivation is of no value as it germinates with the crop. Broomrapes can attach to roots up to 30 cm deep so any soil fumigation must also be deep (8). Hand pulling is not effective as only emerged plants are removed, and the crop has already been damaged.

Clover broomrape is controlled in subterranean clover pastures by superphosphate and grazing (22), and spread in pasture seed is minimised by certified seed schemes (7).

<u>Potential in Australia</u>. Broomrapes have the potential to impact on a wide range of broadleaf crops grown in Australia. Some are listed on Table 1.

Table 1. Major Australian crops likely to be affected by broomrape, *Orobanche* sp. The more (+) the greater the damage

Crop	Broomrape				Source[a]
	crenata	*minor*	*ramosa aegyptiaca*[b]	*cernua*	
Burr medic (*Medicago polymorpha* L.)			++		Pers. obs
Carrot (*Daucus carota* L.)	+++	+	+++		18
Celery (*Apium graveolens* L.)	++		++		
Chickpeas (*Cicer arietinum* L.)	++		++		
Cole crops (*Brassica oleracea* L.)			++		
Cucumber (*Cucumis sativa* L.)			++		
Faba bean (*Vicia faba* L.)	+++	++	++		
Field peas (*Pisum sativum* L.)	+++				
Lentil (*Lens culinaris* Medic.)	+++	+			4
Lettuce (*Lactuca sativa* L.)		++	++		
Lucerne (*Medicago sativa* L.)	++	++			18
Potato (*Solanum tuberosum* L.)			+++		
Rockmelon (*Cucumis melo* L.)			++		
Safflower (*Carthamus tinctorius* L.)		++	++		
Subterranean clover (*Trifolium subterranean* L.)		++			21
Sunflower (*Helianthus annuus* L.)	+	++	++	+++	
Tobacco (*Nicotiana tabacum* L.)		++	+++	++	
Tomato (*Lycopersicon esculentum* Mill.)			+++	+++	
Turnip (*Brassica rapa* L.)			+++		
Vetch (*Vicia sativa* L.)	++	+++			
Zucchini (*Cucurbita pepo* L.)			+		

[a] Based on (8) unless otherwise indicated.
[b] Closely related species often described as *O. mutelii* (8,17).

Australian broomrape. It is likely that Australian broomrape, being mainly restricted to uncleared and newly developed farmland, at least in SA, has not coincided with host crops. Tomato, tobacco and sunflowers are the main host crops of nodding broomrape. Australian broomrape may have a different host preference to the variety of nodding broomrape, (*O. cernua* Loefl. var. *desertorum* Beck.) affecting crops in Eastern Europe and the Middle East (8) through Asia to India (13).

Grain legume crops. The broomrape species posing the greatest risk to the developing grain legume growing industries are not yet in Australia. Faba beans are readily attacked by Egyptian and crenate broomrape (11). There is no record of either species in Australia yet.

The branched broomrape and Egyptian broomrape are very similar, although they vary in their host preference. Branched broomrape plants attached to tobacco twice as readily as Egyptian broomrape (10). The strain of branched broomrape tested did not attach to lucerne, although in Britain it parasitised lucerne (18).

Eradication programs. Recently an eradication program for branched broomrape began in Texas and for clover broomrape in South Carolina (23). Clover broomrape was eradicated from Washington County, Virginia, USA (Foy, pers. comm. 1993).

False hosts have reducing seed reserves of branched broomrape in Texas. Seed per 400 g soil sample declining from 367 in 1984 to 3 in 1990, and 0 in 1991 after annual planting of flax to encourage germination (Westbrooks, pers. comm. 1993).

At Murray Bridge immediately after discovery of branched broomrape in October 1992, we hand pulled all 125 emerged plants prior to seed production. We fenced the 3000 m^2 infested area to stop spread on livestock and vehicles. During 1993 we intend to plant a sacrifice host crop. In September 1993 we plan to destroy it with glyphosate.

Provided we do not find any other infestations we believe the infestation may be eradicated in 10 years. If allowed to spread, it may become an important weed of the grain legume, oilseed, vegetable and seed industries in southern Australia.

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INTRODUCTION AND STATUS OF *KOCHIA SCOPARIA* IN WESTERN AUSTRALIA

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Summary. Within two years of its introduction for use as a salt tolerant forage plant and for saltland rehabilitation, kochia showed weedy attributes by proliferating at planting sites and spreading to non-saline soils. Assessment of its weed potential indicated that it would cause considerable damage to agriculture in Western Australia and, even more so, in summer-grown crops and summer fallows in south-eastern Australia. Recognition of its weed potential led, first, to its proclamation as a Declared Plant in Western Australia and, ultimately, to it becoming an eradication target, under a program funded jointly by Federal and State bodies.

INTRODUCTION

Kochia, *Kochia scoparia*, is an annual chenopod originating from eastern Europe and western Asia. It is a C_4 plant that is competitive under hot, sunny conditions and it has a high water-use efficiency, enabling it to thrive in summer. Well grown plants are dense, multi-stemmed, spherical bushes that may reach 1.5 m in height and diameter.

A weedy form of this species has become a problem in various parts of the world, including most of Europe, parts of temperate Asia, Canada, USA and Argentina (5, 6, 10), but had not been recorded in Australia. The taxonomy of this form is unclear, but *K. densiflora* or *K. scoparia* subsp. *densiflora* may be applicable (P. Wilson, pers. comm., 1992). An ornamental form, known variously as summer cypress, mock cypress or burning bush, *K. scoparia* var. *trichophylla*, is distinct from the weedy taxon and has been grown in Australia for many years.

Problems associated with kochia are its competitiveness in a wide range of agricultural and horticultural crops, invasion of pastures, allelopathic effects on pasture and crops plants, toxicity to stock, and infestation of roadsides and railway reserves (1, 3). It is also noted for its rapid spread, which results from the 'tumbleweed' nature of dead, seed-laden plants (3). It has developed resistance to sulfonylurea and triazine herbicides as a result of rep
eated treatment (1, 7, 8).

Despite its well documented weediness, there has been considerable interest in cultivating kochia as a forage plant, on account of its palatability, rapid growth, high productivity and ease of establishment (2, 4). Its ability to flourish in saline soils led to its recognition as a potential forage plant for use in salt-affected soils in Australia. It was introduced into Western Australia in 1990, but by early 1992 it had begun showing weedy behaviour by spreading from planting sites.

This paper reviews the introduction of kochia into Western Australia, its progress during two years of cultivation, and the intervention by the State's Agriculture Protection Board (A.P.B.), the Department of Agriculture and the Australian Quarantine Inspection Service (A.Q.I.S.) aimed at preventing kochia becoming established as a weed in Australia.

METHODS

Abstracts of literature on kochia were obtained from the Commonwealth Agricultural Bureaux (C.A.B.) database for the period 1973-91.

Individuals to whom kochia seed had been sold were traced through sales records supplied by the Perth-based seed merchant who imported the seed in mid 1990. They were contacted by phone in early 1992 to determine the progress of plantings. This led to field surveys in autumn 1992. Further surveys of known plantings were conducted in spring and early summer 1992 to determine the amount of regeneration from seed, the extent of spread within and beyond the planting site and the environmental conditions of the site.

RESULTS AND DISCUSSION

Literature profile. Of the 208 references on this plant in C.A.B. Abstracts for the period 1973-1990, two thirds dealt with its deleterious attributes (Fig. 1). The literature also provided information on the plant's biology.

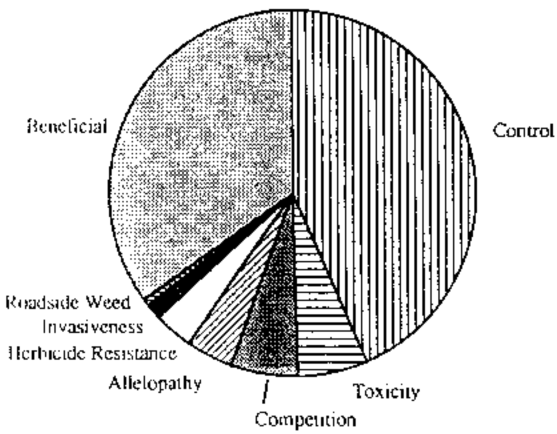

Figure 1. Literature on kochia from C.A.B. abstracts for the period 1973-1990, categorised by topic.

Introduction and ultimate distribution. When the seeds of kochia were imported into Perth from United States in May 1990, there was no reason for A.Q.I.S. to doubt the claims made regarding the usefulness of kochia for rehabilitating salt-affected land. Since the plant was not prohibited under Federal or State legislation, its importation was allowed.

Plantings were made in 1990 on a small number of farms in Western Australia, mainly for the production of commercial quantities of seeds. By late 1991, kochia had been planted at 68 sites throughout the southwest of Western Australia. Almost without exception, the plantings were in salt scalds that the landholders were keen to rehabilitate. The plantings were located throughout the wheatbelt, with two in adjoining pastoral regions. No seeds were distributed beyond Western Australia, apart from two consignments that were sent to Victoria, of which one failed to germinate and the other was not planted.

In most cases, the seed was sown as a component of a mixture, in which the other species were salt-tolerant perennials including saltbush, *Atriplex* spp., acacia, *Acacia saligna*, and the grasses puccinellia, *Puccinellia ciliata*, and tall wheat grass, *Agropyron elongatum*. Several farmers who purchased seed had not planted it, while in other cases the seed failed to germinate or else the planting was destroyed by grazing while plants were immature.

Surveys. Field inspections throughout 1992 showed that kochia was growing actively at 52 sites in all parts of the wheatbelt where it had originally been introduced. The spring 1992 survey revealed that kochia seedlings were present at practically all sites that had contained mature plants the previous autumn. Seedling densities were often high, reaching several thousand seedlings/m^2. This indicated a high level of seed production within the planting site, since these seedlings were clearly not derived from the original sowings. Most infestations were small (Table 1). The majority were less than 10 ha in extent and, within that size class, most occupied 0.1-5 ha, reflecting the limited size of the original sowings in salt-affected sites.

Table 1. Size distribution of kochia infestations, December 1992

Size class (ha)	Infestations (n)	Size class (ha)	Infestations (n)
0.1 - 10	38	61 - 70	0
11 - 20	4	71 - 80	1
21 - 30	5	81 - 90	0
31 - 40	0	91 - 100	1
41 - 50	2	101 - 110	0
51 - 60	0	111 - 120	1

Seedlings were not restricted to saline soils, but were found on a range of soil types, including non-saline agricultural soils and an alkaline 'kopi' soil of pH 8.8 (9). In most cases, the seedlings were growing within the salt scald, but there were several instances where they occurred in crops (specifically barley and lupins) and pasture adjoining the scald. Others grew in nearby firebreaks, ditches and tracks, and along fences where the parent tumbleweed had stopped. These findings indicated the weed's adaptability and its potential to invade a wide range of soil types and land use.

One limitation of the spring 1992 survey was the small size of seedlings (most were <5 cm tall), which made their detection difficult, especially when they were present at low density. When some sites were examined again in January 1993, after plants had grown substantially, isolated plants could be found some distance away. The most extreme examples of this were at Jerramungup, in the southern wheatbelt, where the sizes of two infestations that were recorded as occupying less than 10 ha each when assessed in spring 1992, were revised to 750 ha in January

1993 when large plants were found in adjoining paddocks, in one case up to 3 km from the original planting. These examples also illustrate the plant's ability for rapid spread, following its initial sowing in 1990.

Declared plant status. Within a few weeks of the magnitude of the weed potential of kochia being realised, the A.P.B. gazetted kochia as a Declared Plant (noxious weed) in April 1992, placing it in the P4 (containment) category which required landholders to prevent its spread. This was an interim classification, pending further evaluation of the suitability of placing kochia in the eradication category. Declaration led to various control measures at all known plantings, aimed at preventing dead plants breaking off and spreading from the existing plantings. At that time an intense publicity campaign was undertaken to alert growers to the risks posed by kochia and to invite reports of suspect plants.

The declaration status of kochia was upgraded to P2 (eradication) in December 1992, in response to the widespread germination at planting sites and evidence of spread of the weed. It was also considered to be a suitable candidate for eradication because of its re
cent introduction, its limited but well documented distribution, the high degree of farmer support and the limited longevity of its seeds, which appear to lose viability after 18 months (A.H. Cheam, pers. comm., 1993).

Potential distribution. The potential distribution of kochia was predicted by bioclimatic matching, using climatic profiles for locations overseas and in Western Australian where the plant had been recorded. The resulting prediction indicated that most of southern Australia was climatically suitable for kochia, including the major cereal growing regions of all southern mainland States (S. Connell, pers. comm., 1992). Overall, kochia might be an even greater threat to south-eastern Australia than to Western Australia. This is because its prevalence as a weed in a wide range of summer-grown crops in the United States (3) suggests that it would be of particular concern in those parts of south-eastern Australia where crops are grown in summer. It is also highly likely that kochia would flourish in summer fallows, depleting the soil moisture reserves required for subsequent crops.

Eradication program. In view of the perceived threat to Australian agriculture as a whole, and the weed's current restriction to Western Australia, joint Federal (A.Q.I.S.) and State funding for a four-year eradication program for kochia was approved in March 1993. As a result, a vigorous program of herbicide treatment, crash grazing and grubbing was conducted at all known infestations in autumn 1993, with the aim of preventing seed production by destroying all known kochia plants (B. Uren, pers. comm., 1993).

A commitment to monitor known infestation sites, to search adjoining areas for any missed plants and to continue with publicity to help locate any new infestations should guarantee the success of the eradication campaign and protect Western Australia and other parts of Australia from this recent, undesirable introduction.

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THE SPREAD OF BUFFEL GRASS IN INLAND AUSTRALIA: LAND USE CONFLICTS

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Summary. Buffel grass has spread along road sides, river systems and into sheltered mountain habitats in central Australia. It is altering the biological integrity of many of these systems and may affect future native mammal re-introduction attempts. It is occupying restricted moist habitats in the ranges where most of our rare and relict native species occur. There are few options to limit further spread. The invasion provides important lessons for assessing new introductions and controlling species targeted for particular areas.

INTRODUCTION

Buffel grass (*Cenchrus ciliaris*) is widely distributed across northern and inland Australia, established from early accidental introductions and many programs of deliberate propagation for erosion control and pasture improvement (14, 2). There is no evidence to suggest that the likely spread or impact of the species to non-targeted areas was ever given consideration. It is now spreading, un-aided, into many areas that were never targeted for its establishment (8). Grass invasions throughout the world have often had devastating consequences (5).

Buffel grass is propagated in many areas in central Australia (8, 1). It had a restricted distribution for most of the time it has been established in central Australia. It spread rapidly during high rainfall periods and extensive flooding in the 1970's. Buffel grass now dominates most river frontage areas with self-maintaining populations, altering fire regimes and displacing food plants for native animals (12). It is dense in significant conservation areas of Uluru National Park (7). It is a major threat to food plants of Aboriginal people (10).

The establishment and spread of buffel grass raises at least two important issues to land managers. First, the criteria by which potential introductions are assessed do not include the invasive potential of the species into rangelands and conservation areas. Second, before species are established on target areas, mechanisms for limiting undesirable spread need to be in place.

I show how and where buffel grass has spread through areas of mountain ranges of central Australia. I discuss the conservation significance of the invasion and highlight some issues of introductions in rangeland and conservation areas.

METHODS

Data were collected from an extensive area of mountain ranges in central Australia. The data comprise presence records of buffel grass on different geological units and in different topographical positions on those units. I examine the frequency of records according to geology and topography.

During 1991 I sampled 308 one-kilometre transects within the central mountain ranges. On each transect I recorded if buffel grass was present within a site of 20 m radius at every 50 m interval along each transect. I recorded the location for each transect in AMG co-ordinates. At each record site I noted geological and topographical data to correlate with the occurrence of buffel grass. Each transect was confined to a geological unit so I have only recorded here if buffel grass was present on a unit. I have classified the units into fewer rock types. The mean values of a range of oxides for each rock type were calculated from data available from the Bureau of Mineral Resources. No geochemical data were available for alluvial sites. The site topographical data were used to determine if the presence of buffel grass was associated with particular morphological features. I classified morphological features into common landform types. I calculated annual solar radiation levels of sites.

RESULTS AND DISCUSSION

Buffel grass prefers alluvial soils and rock types that are low in SiO_2 and high in CaO (Table 1). These rock types generally provide alkaline soils richer in nutrients than sandstones and quartzites. These results are consistent with the other findings (4) that buffel grass generally fails to establish on acidic soils.

Table 1. The percent frequency of buffel grass on rock types and the mean percent by volume of oxides in the rock types

Rock type	Frequency	Mean percent by volume of oxides								
		Al_2O_3	CaO	Fe_2O_3	K_2O	Mgo	Mno	Na_2O	P_2O_5	SiO_2
Alluvium	86	-	-	-	-	-	-	-	-	-
Gneiss	51	10.0	3.1	3.7	2.3	1.6	0.0	1.7	0.0	44.7
Dolomite	33	5.4	3.1	1.9	3.5	3.0	0.4	0.6	0.4	54.4
Limestone	27	7.1	5.2	4.8	2.2	4.7	0.3	1.0	0.3	26.6
Quartzite	7	7.9	1.6	3.1	2.5	1.3	0.3	0.9	0.4	76.4
Sandstone	6	5.8	2.5	2.5	2.4	1.7	0.4	0.5	0.6	79.0

Lower parts of drainage systems and alluvial flats, particularly flood-outs, are preferred landforms for buffel grass (Table 2). It was frequent on cliffs, ledges and benches. These habitats in the higher parts of the mountains are sheltered from high solar radiation levels (Fig. 1).

Buffel grass is very common about the town of Alice Springs (Fig. 2) where it has spread from intensive plantings (9) by means of wind and water. Where it occurs on sites distant from Alice Springs it is predominantly in drainage systems and on alluvial flats. The spread of buffel grass along drainage systems is consistent with recordings of its habitat preference in other areas of Australia (8). The drainage systems are those areas where cattle grazing is most common and floods frequently disturb the soil surface.

Table 2. Percent frequency of buffel grass in different landform types in the mountains of central Australia

High ridges		Hill slopes		Drainage systems		Alluvial flats	
Ledge	32.0	Cliff	20.7	Head-waters	22.3	Flood-out	69.7
Bluff	5.2	Bench	22.6	Creek	23.2		
Peak	8.7	Slope	5.5	River	37.5		
		Shoulder	4.9				

It is unlikely that cattle are responsible for significant spread of buffel grass since seeds rarely survive ingestion (6). Evidence from Uluru National Park (7) suggests that transport of seed along road corridors is largely by wind generated from vehicles.

Buffel grass is established or spreading into habitats critical for conservation in central Australia. Its establishment in the very restricted habitats of shaded cliffs and gorges in the hills brings it into direct competition with many of the known rare and relict plant species of central Australia (3, 11). Its dominance along the lower drainage systems is altering the habitats known to have harboured many small mammals that have gone locally or globally extinct in Australia (13). Alteration of these rich areas may limit attempts to re-introduce many mammal species to their former habitats.

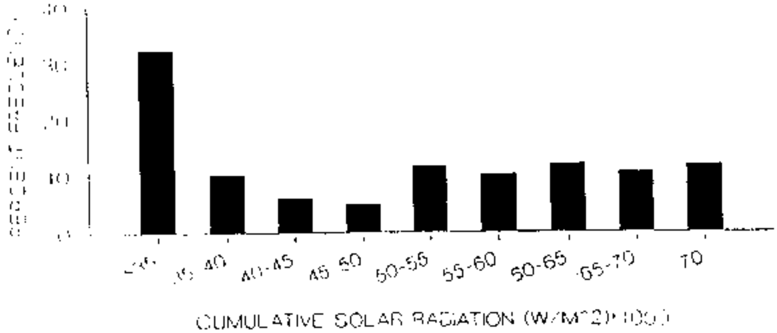

Figure 1. Percent frequency of buffel grass on sites with different levels of annual solar radiation.

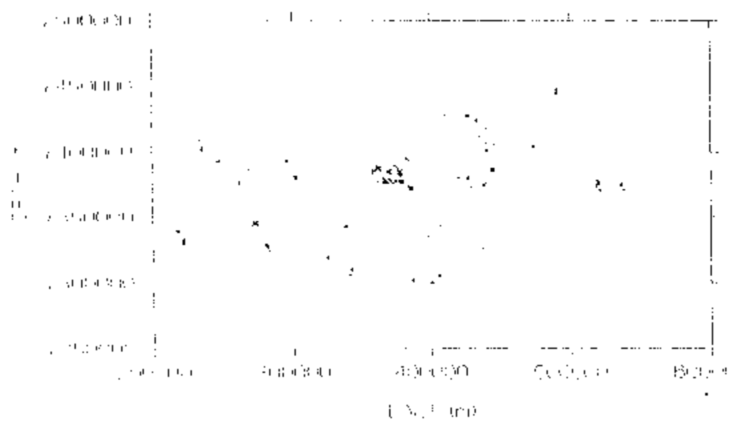

Figure 2. Map of the distribution of transect samples showing the occurrence of buffel grass. X = present on creeks and flats, □ present on hills, ◂ = absent on creeks and flats, ▸ = absent on hills. Alice Springs is located at approximately 385000E 7377000N.

Weed status

Trading off the perceived positive effects of introduced species against the negative effects requires that the effects are understood and considered. Agricultural or horticultural criteria are largely used for assessing species for introduction into Australia. I suggest that any future assessments need to take much greater account of the impact of species in natural rangelands and conservation areas. Strong and growing public concern for the maintenance of biodiversity may sway opinion against more introductions that could homogenise our biota (15). We need alternatives to conventional introductions.

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RAMPION MIGNONETTE AND ITS CO-ORDINATED CONTROL

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Summary. Rampion mignonette, *Reseda phyteuma* L., is an annual to short lived perennial agricultural weed from the Mediterranean, new to Australia. It has the potential to spread and increase agricultural production costs in southern Australia. Rampion mignonette is well adapted to the climates of southern Australia and New Zealand, and if not contained may become a widespread weed. Eradication may succeed.

INTRODUCTION

Every year new plants become naturalised in Australia. Some newly introduced plants spread and become major weeds. Other have limited impact. Early eradication of a weed will prevent it causing widespread problems (25), however our record of predicting and stopping potential weeds soon after introduction is poor (3,12).

Species unknown in Australia with a similar biogeographic range to plants invasive in Australia may be potential weeds (5,6).

Predictors of potential weeds include the experience in other regions with similar climates (14,17,25), the plant's native distribution (4,6), the behaviour of related taxa (25), seed production and germination (6) and the number of introduction points (6). Competitive ability may also predict the potential to cause problems in a new environment (13).

This paper reports on the potential of the recently introduced plant, rampion mignonette, *Reseda phyteuma* subsp. *phyteuma* L. to spread and impact on agriculture.

<u>Importance of rampion mignonette</u>. Rampion mignonette is an annual to short lived perennial herb (1). The subspecies is native to north Africa and southern Europe (1,3) and is a weed of dryland wheat, chickpeas, faba beans (8), vegetable fields (16), maize (7) and vines (1,2,15), but is not a major weed. In Portugal it is restricted to walls, rocky places and roadsides (Ribeibo pers comm, 1990). It is not a major weed outside of its native range (9) but has spread to northern Europe (24). Rampion mignonette is not on weed lists from North America (23), South Africa (22), Iran (10) or New Zealand (21).

<u>Rampion mignonette in Australia</u>. The first record of rampion mignonette in Australia, was from Nagambie, Victoria (36°47'S, 14°10'E) in 1985 (Cade, pers comm, 1985). It was eradicated within two years (Montgomery, pers. comm. 1991). The introduction was attributed to imported lucerne seed planted in 1980 (18). The lucerne crop failed and was followed by three successive wheat crops. In 1984, when the area was sown to irrigated pasture grasses, rampion mignonette appeared in isolated patches. Stock would not eat it and the owner removed all plants (Cade, pers. comm. 1985). It also appeared in an adjoining paddock planted to lucerne in 1986. The few plants found were destroyed by the land-owner. It last appeared in 1987 (Montgomery, pers. comm. 1991).

The second record was from Clare, SA (33°50'S, 138°37'E) where it was collected in 1987 after it escaped under-vine herbicides. Unfortunately it was wrongly determined as the garden escape sweet mignonette, *R. odorata* (2). It was only in 1989, after further spread, that specimens were determined as rampion mignonette (Heap, pers. comm. 1989). By 1990 when it was first surveyed it covered five non-contiguous vineyards over 38 ha (2).

METHODS

On visits to the Clare infestation between September 1990 and December 1992 I observed rampion mignonette in vineyards, roadsides, pastures and tree reserves. I obtained management history from land-owners.

I used the literature (1,24) and herbarium records to map the native range of rampion mignonette and matched climates from 29 sites from the native range of subspecies *R. phyteuma* in north Africa and south-west Europe, with climates of Australia and New Zealand using CLIMEX version 4.2 (20). I chose recording stations close to collection sites from herbarium records (Fig. 1). Climates with a match index equal or more than 0.7 are a good match (17).

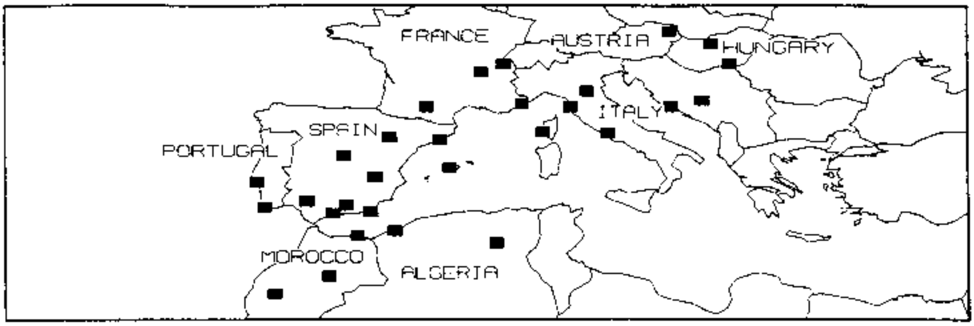

Figure 1. European and North African range of rampion mignonette, *Reseda phyteuma* subsp. *phyteuma*, including sites used for climate matching.

RESULTS AND DISCUSSION

Climate matching. The climate of the Western Australian wheatbelt, and south-eastern Australia, is similar to that of the native range of rampion mignonette. The predicted range also includes the major vineyard areas in Australia. In New Zealand the climate of Napier in the North Island, and parts of the South Island match the native range (Fig. 2).

The Australian infestations of rampion mignonette occur at sites which match with its native range. Clare matches with Rome, Italy (match index = 0.72) while Mangalore, 15 km from Nagambie, matches Barcelona, Spain (0.70) and Toulouse, France (0.73).

Distribution in Europe. Figure 1 shows the native range of *R. phyteuma* spp. *phyteuma*. The native range of the sub-species suggests it is adaptable and will become a significant weed in Australia. The European range is broad indicating a potential to spread quickly (4).

Biology. Seed biology and morphology suggest that rampion mignonette is invasive. Invasive species germinate rapidly but have seed dormancy (6). The preliminary biological studies indicate that rampion mignonette is a prolific seeder (18) and field observations suggest that it germinates over an extended period (19).

Resistance to cultural practices. Rampion mignonette causes most problems in vineyards where herbicides are used for weed control, but will also dominate under the vine where herbicides are not used between the rows. It resists current cultural practices in vines, including triazine herbicides, and its seedlings emerge all year, escaping glyphosate. It invades well managed vineyards at Clare. Agricultural weeds which resist herbicides increase when herbicides are used frequently (11).

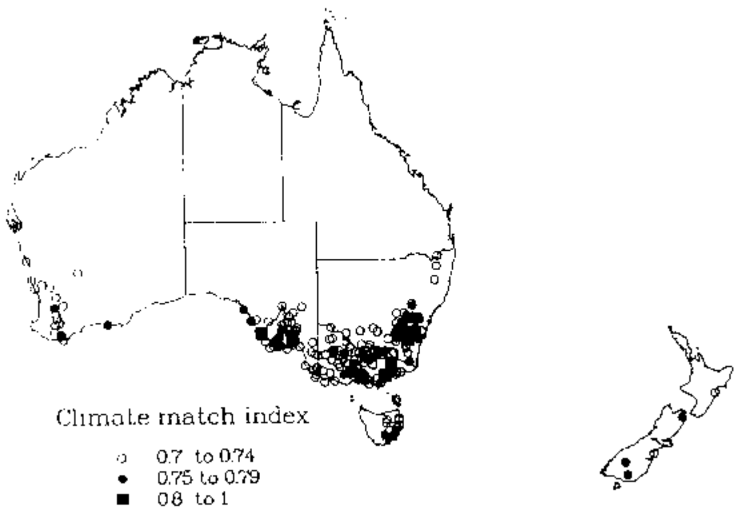

Figure 2. The potential range of rampion mignonette, *Reseda phyteuma* ssp. *phyteuma* in Australia and New Zealand. Match indices > 0.7 are a good match.

At Clare it is also present in a relatively poor volunteer pasture. It is eaten by sheep, but is not preferred. This allows it to dominate under selective grazing. In SA it has not yet spread to cropped paddocks. Tolerance to herbicides may enable rmpion mignonette to become a weed of many annual crops as well as horticulture in southern Australia.

Ability to spread. Rampion mignonette is easily spread and will soon spread to other vine growing districts. It has already spread from one vineyard near Clare to a second under the same management, 7 km away. After field inspections, mud washed fromm boots contained seeds and pods (Heap, pers. comm. 1989). The frequent movement of workers, vehicles and machinery between vine growing districts will enable rampion mignonette to spread.

Coordinated control. A control program for rampion mignonette should proceed because the climate matching indicates it could become widespred in southern Australia; and secondly, the tolerance to triazine herbicides and ability to escape other treatments will enable it to compete with a range of horticultural and annual crops and thirdly, its broad native range and the initial spread within the Clare suggests that it will spread rapidly within Australia.

Weed status

There are two possible aims for a coordinated control program. A *containment* program aims to prevent further spread from the infested areas by regular treatments and local quarantine. The alternative is *eradication*.

Containment program. In 1991 the Animal and Plant Control Commission began a containment program by proclaiming it under the *Animal and Plant Control (Agricultural Protection and other purposes) Act, 1986* and *Seeds Act, 1979-82*. The containment program is locally funded. Landowner are required to destroy rampion mignonette on their properties. A local control board oversees the operation. Landowners are co-operating by spraying any plants with glyphosate (Conrade, pers. comm. 1992). A colour brochure was produced and a publicity campaign including all vineyard areas in South Australia commenced in 1992.

Eradication program. To move from containment to eradication will require extra resources to study rampon mignonettes biology, develop control techniques, carry out control and compensate affected landowners for lost production due to eradication treatments. An eradication program has the advantage that it has no annual cost after eradication.

There are two reasons why eradication is likely to succeed. Firstly, the only Australian infestation is still small and secondly, the successful eradication of the Nagambie infestation suggests it is technically possible to eradicate rampion mignonette.

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