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ENVIRONMENTAL IMPACT OF WEEDS

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Summary. Plant species which have spread outside the limits of their natural geographic range as a result of intentional or inadvertent human activities have invaded native communities with unwelcome effects. Shifts in plant species abundance, often with severe reductions in natural diversity, are the most overt effects of successful invasions. More subtle and far-reaching are fundamental alterations to ecosystem function including nutrient cycling, hydrology and disturbance regimes such as fire. The nature and severity of the effects of individual species varies from insignificant to major depending on the attributes of the species involved and the vulnerability of the system to invasion. The latter is closely linked to human mediated disturbance. The extent of the impact is dependent on the potential area for colonisation by a given species and is a non-linear function of time since its introduction. Most naturalised species do not have attributes which lead to serious environmental consequences, but of the small proportion that do some are capable of irreversible destruction of native populations and alteration of the structure and function of the host system. In Australia a relatively small proportion of exotic species introduced, most of them deliberately, have collectively initiated continent-scale processes of biological impoverishment and ecosystem degradation. Indications are that the situation will continue to deteriorate but the scale of research effort does not match the severity of environmental impacts occurring. The possibility of long-term mitigation rests in the management of the underlying disturbances, and a shift away from the weed as the primary focus of attention. To these ends research needs to focus on: (i) more comprehensive and quantitative documentation of the potential ecological destructiveness of invasive plants; and (ii) elucidation of the specific linkages and feedbacks between human activities and the introduction, establishment, and spread of priority weed species.

INTRODUCTION

My intention here is to present an overview of the nature and range of ecological consequences which exotic plant invasions can induce and the current status of invasions on the Australian continent. In doing this I hope to illustrate the importance of this phenomenon for conservation of biological diversity and thus to encourage studies which increase our understanding of the full impact of plant invasions and the conditions that promote them.

Australia's biota and native ecosystems are changing as human activities increasingly introduce and assist the establishment of plant species outside their natural range (see 22 for a recent review). Although communities are intrinsically dynamic and change is inevitable, the post-industrial acceleration of change toward homogenisation of plant communities is generally regarded as unacceptable. Since the SCOPE (Scientific Committee on Problems of the Environment) initiated studies of the 1980's (e.g. 8,16), plant invasions are recognised increasingly to be among the most pervasive processes of impoverishment of natural diversity. As such, they are a critical issue for conservation. Soulé (38) in his presidential address to the Society for Conservation Biology in 1989, listed (1) climate and ecosystem processes, (2) habitat fragmentation, (3) community truncation, (4) restoration and (5) biological invasions as the major challenges for conservation biology in the coming decade.

TERMINOLOGY

An introduced species is here defined as one which occurs away from its natural geographic range as a result of intentional or inadvertent transport by humans.

Introduced species that are capable of establishing self-sustaining populations are referred to as 'naturalised' and if this occurs in natural or semi-natural vegetation they are classified as 'invasive'. Natural or semi-natural vegetation refers to largely untransformed ecosystems; here I include disturbed systems that still maintain the main elements of the original community structure, such as extensively grazed rangelands. 'Weed' is a broad, loosely used term that applies to any plant growing out of place.

WAYS IN WHICH INTRODUCED PLANTS CAN AFFECT NATURAL SYSTEMS

Studies of invasions do not catalogue all the direct and indirect effects of the new species on the plant and animal community and the ecosystem properties. What we have are selected ecosystem processes and properties and examples of one or more invaders that are capable of altering these. We have a composite picture of possibilities from observations on many invaders from around the world.

The potential of invasive plants to affect both ecosystem structure and function is enormous. Some of these effects are self-evident, others are subtle or manifest only with time. Structure here means species composition (plant and animal), relative species abundance, the physical structure of the vegetation assemblage and the trophic structure of the animal community. Ecosystem function refers to the underlying processes of ecosystem maintenance and disturbance such as mineral cycling, decomposition, hydrological cycling, and fire regime.

The most deleterious invasive species form a virtual monoculture, successfully colonise a range of localised environmental conditions, have a broad geographic range and the changes they initiate are irrevocable.

Changes to ecosystem structure. Changes to native species abundance are the most conspicuous impacts of exotic plant invasions on ecosystem structure. The transformation to the community can be so striking that no doubt remains that the invader is having an effect.

The displacement of native species by a monoculture or near monoculture of exotic species has a self-evident effect: gross reduction or even local extinction of native species. There are no documented instances of absolute extinctions of native species because of plant invasions. The possibility has been inferred for areas poorly known biologically and likely to be of high endemicity.

Direct alteration to vegetation structure is not uncommon. Prickly acacia, *Acacia nilotica*, which is invading thousands of square kilometres of the Mitchell grasslands of northern Australia is gradually turning a naturally treeless community into a shrubland. The giant sensitive plant, *Mimosa pigra*, is transforming open grass-low shrub floodplain communities into impenetrable shrub thickets up to 6 m in height (27) in the river systems around Darwin. The blue thunbergia vine, *Thunbergia grandiflora*, which colonises lowland rainforest edges of far north Queensland has the capacity to fell forest remnants (23). The highly vigorous vine totally blankets trees, eventually killing them. These subsequently rot and the forest patch is progressively felled from the edge. The inter-tidal cordgrass, *Spartina* spp., introduced from the United Kingdom is changing bare mudflats into dense meadow habitat mainly in Tasmanian and Victorian estuaries (9).

Indirect changes to structure are usually inferred because the process is not complete due to the time scales of invasion and response involved. The spread of mission grass, *Pennisetum polystachion*, is threatening the recruitment of mid-story tree-species in the monsoonal savannas of the Top End (6) due to changes to the fire regime brought on by the grass. The structural change will only become manifest on a time scale of years as adult trees die. Inhibition of recruitment of native shrubs and trees by grass and herb invasions is reported for southern Australian forest remnants (21, 36). These opportunistic species have high relative growth rates and compete vigorously for available surface moisture. Interruption of succession by exotic grasses through competition for water is also documented by researchers in other systems (e.g. 10, 30, 37).

Changes to vegetation structure can translate into significant changes to fauna habitat which in turn can cause local change in fauna density. The change can be positive as was found by Braithewaite and Lonsdale with the small mammal *Sminthopsis virginiae* (6) in *Mimosa pigra* infested areas. Or, structural change can cause significant decline in vertebrates and invertebrates as was found by Griffin *et al.* (14) after the invasion of the tamarisk, *Tamarix aphylla*, in the Finke River, central Australia. *Spartina* infested mudflats have reduced numbers of wading birds and invertebrates (9).

<u>Changes to ecosystem function</u>. Changes to processes associated with invasions are rarely measured; more usually they are qualitatively described or inferred. Australian studies are notably few and many of the descriptions are taken from overseas studies.

Alterations to the geomorphological and hydrological processes. Introduced species have been demonstrated to affect geomorphological processes such as fluvial geomorphology, sedimentaion and soil erosion, and sand dune geometry; processes which shape landscapes and habitat characteristics.

The phraetophyte tamarisk (athel pine, saltcedar,*Tamarix* spp.), introduced to the arid south-west USA in the mid-1800's from Eurasia, was common in most major drainage systems by 1920. Today the woody perennial forms thickets of thousands of hectares along these rivers where it acts effectively as a geomorphic agent. It replaced indigenous vegetation that was repeatedly swept away by floods and by contrast persisted on unstable surfaces, withstanding inundation and inducing sedimentation. Its impact on fluvial geomorphology was documented by Graf (11) who reports that colonisation by the tree-shrub results in stabilisation of underlying surfaces, longer and wider islands, wider channel-side bars and expanded alluvial fans. A concomitant reduction in channel width of 13-55% increases frequency of overbank flooding. *Tamarix* spp. were introduced to Australia in the late nineteenth century and only became invasive in the mid-1970's. The invasion is too recent for major geomorphological changes to have developed but the potential is there (14).

Cordgrass from the genus *Spartina*, accidentally imported from North America last century, changed the face of intertidal salt-marshes around the British Isles and other countries (40). The dense stands this grass produces are famed for their ability to accrete and consolidate large volumes of tidal sediment and have been used for land reclamation purposes. Accretion rates of

5-10 cm per year cause a rapid rate of rise of the marsh surface - 70 cm in 60 years and 100 cm in 50 years are reported from the south coast of England. The plant was introduced to southern Australia about a century ago for land stabilisation but its spread is now recognised as a major ecological problem (9).

Sand dune geometry has been markedly altered by grass species such as *Ammophila arenaria* introduced world-wide for sand stabilisation but which inevitably escape their target areas. On the west coast of the USA, the grass has changed inland sand-dune orientation from the original perpendicular to the coast to parallel to the coast and foredunes changed from low, gradually rising to steep (3). Changes to coastal topography induced by exotic grasses are reported for Africa (29) and Australia (18).

Invasive plants can alter the hydrological conditions within an ecosystem in ways which are in addition to the directly competitive strategies for exploitation of available moisture.

Grasses can alter drainage patterns; this is readily observed in the wet tropics where the introduced para grass, *Brachiaria mutica*, is choking lowland streams and shallow swamps. It and other introduced ponded pasture species are converting open water into wet grasslands (22). The perennial bunchgrass, *Andropogon virginicus*, in the montane rainforest communities of Hawaii is doing the opposite. Its low transpiration rates, phenology and litter characteristics relative to native species reduces water removal and creates swampy areas (31). The water hyacinth, *Eichhornia crassipes*, apart from its ability to choke water bodies with its prolific potential production of in excess of 1 tonne of dry mass per hectare per day, transpires water at a rate of up to 7.8 times that of evaporative rates from open surfaces (33). Water hyacinth is largely controlled in Australia but outbreaks are always a threat.

The tamarisk, *Tamarix* spp. described above, is a rapidly growing (up to 4 cm d^{-1}) tree-shrub with roots that reach the water-table. It has very high rates of evapotranspiration and can lower the water table with disastrous local consequences. It reduces the area of open water which affects migratory waterfowl, aquatic habitat and water sources for vertebrates (28).

Alterations to the fire regime. The alteration of the fire regime leads predictably to modification of the native vegetation. Fire affects vegetation communities depending on the attributes of the species present, fire frequency, intensity, seasonality and extent.

Introduced grasses around the world are accompanied by altered fire regimes, which in turn set up a positive feed-back encouraging further grass invasion. This interaction between fire and invasion is probably the most ecologically significant effect of exotic grasses. Fuel properties change with bulkier tussock formations, more continuous groundcover and different curing rates that tend to distinguish the successful introduced species from the native counterparts.

Australia has a number of grass species regarded as a severe conservation threat (22). Buffel grass, *Cenchrus ciliaris*, is deliberately planted throughout much of inland Australia. It is well adapted and aggressively colonises moist habitats such as run-ons, river levees and alluvial pans where it forms dense, continuous monocultures. The flammable material produced is 2-3 times that of the displaced native grasses and cures later in the year (25). The result is much hotter and larger fires later in the season. Infested rivers banks act as wicks spreading fires further so the patchiness, characteristic of traditional burning regimes, is lost. Native eucalypts are scorched and there are signs that successive fires could kill them (Latz pers. comm.). The different timing and intensity of the fires has implications for recruitment of native species (12, 13). For example, acacias are vulnerable to increased frequency of fire as they rely on seed for recruitment and if they are burned twice before they seed, do not recruit.

Mission grass, *Pennisetum polystachion*, a vigorous perennial grass from West Africa is a major threat to the eucalypt and deciduous pantropical tree species unique to the northern Australian savanna. It is replacing the native annual *Sorghum intrans* which is far less dense and cures earlier in the year. The fires following mission grass colonisation are hotter and occur later in the year. This tends to result in the removal of mid-height vegetation, thereby simplifying vertical structure, decreasing the abundance of fruit resources, increasing scorching of trees and leading to possible increase in tree death rate (5).

The changes brought about by the changed fire regime can be self-generating. Often recruitment of the introduced grass is differentially favoured by the fire. In south-western Australia veldt grass, *Ehrharta calycina,* invades forests after fire which is promoted in turn by the increased fuel load of the grass, thereby establishing a cycle favouring further invasion (2, 7). Molasses grass, *Melinus minutiflora,* greatly increases fire intensity around rainforest edges and has established a similar cycle on the hillsides around Cairns, Queensland. The hills manifest huge fire scars along the entire coastal strip where the grass-induced fires have pushed back the forest edge (23).

Lantana, *Lantana camara*, a widespread weed in the Australian wet tropics and elsewhere, has a role in the fire ecology of rainforest edges (42). It changes fuel characteristics in a complex way which varies with a range of factors including topography, wind and moisture content of the vegetation. However, during hot, dry, and windy conditions, lantana burns intensely and damage to the forest edge may occur. The situation is exacerbated if exotic grasses are mixed with the lantana. In mild fires, however, lantana has been observed to act as a protective barrier to fire.

Alterations to mineral cycling. Substantial alteration of nitrogen cycling has been documented in open-canopied forests of Hawaii where the exotic nitrogen-fixing tree, *Myrica faya* is established. A quadrupling of availability of nitrogen has been estimated by Vitousek (43). The community implications of the increased availability of nitrogen will become evident with time. One result is that exotic earthworms are two to eight times more abundant than under native trees (1).

Lantana, *Lantana camara*, also fixes nitrogen but to my knowledge, its contribution to the ecosystem resource base or the effects have not been estimated. The soil under lantana thickets is noticeably more friable and richer in organic matter than that in nearby native communities, suggesting that the plant promotes soil organism activity and rapid rates of soil regeneration.

Indirect evidence of affected nutrient cycling is provided by the changes to soil salinity brought about by tamarisk, *Tamarix* spp., invasions. The plant is extremely salt-tolerant with salt concentrations in foliage up to 50 times that in the root water supply (4) so that the leaf litter is highly saline. It is also well compacted due to the packing characteristics of the needle-like leaves. In the Australian study of Griffin *et al.* (14), invertebrate fauna in the leaf litter was found to be sparse and depauperate in tamarisk stands compared with the diverse and abundant fauna in the native river red gum stands. One can infer from this that the rate of nutrient cycling will be considerably impaired with flow on effects to both the plant and animal communities. Re-distribution of salt from the rooting zone to the soil surface by the ice-plant

Mesembryanthemum crystallinum has led to soil erosion through the inhibition of native pasture species which bind the soil (24).

Concluding remarks on alterations to ecosystem function. The above is not an exhaustive list of the ways in which introduced plants can affect the function of natural ecosystems.

Changes to productivity, biotic interactions (e.g. predation, seed dispersal), hybridisation and allelopathy are other processes which invasions can potentially induce. Hybridisation by two *Spartina* species eventually led the vigorous hybrid which is now rampant in the UK (41). In Australia, the high potential for hybridisation is among the strongest ecological reasons for minimising use of translocated native species for revegetation purposes. Similarly the introduction of non-native species for commercial forestry plantation is introducing the possibility of hybridisation. For example *Eucalyptus europhylla*, a tropical timber species currently on trial in far north Queensland is known to be able to hybridise with the native *E. grandis* (23). Invasion-related changes to primary productivity have not been measured to my knowledge in terrestrial systems but changes to secondary productivity have been inferred, for example with respect to waterfowl in *Spartina* invaded communities (9). Alterations to recruitment rates of native species and successional sequences after disturbance are implicitly or explicitly dealt with in the foregoing discussions.

It is likely that for any known ecological process an invasive plant could be found to illustrate how it can be perturbed. Very few of these ecological impacts have been studied and the examples only serve to demonstrate the potential for the range of effects possible and for the subtle nature of many of them. Also significant are the long time frames required for some of the consequences to manifest themselves.

I also wish to draw attention to the many ecological impacts a single species may have. One that has been relatively well documented as an example is tamarisk, which profoundly affects regional geomorphology, hydrology, the native plant community, the invertebrate and vertebrate community, and litter decomposition. Most of the seriously invasive plants probably completely alter an ecosystem in a myriad of ways but these remain undescribed.

IMPACT OF INVASION IN AUSTRALIA

About 11% of Australia's 17000 or so vascular plant species (19) are naturalised; about half of these invade natural vegetation and of these about half are serious or have the potential to be so (22).

Despite the small proportion of introduced plants that become a major environmental problem, the Australian experience, as elsewhere, has been that a single species is capable of substantially and irrevocably modifying or wholly destroying an ecosystem. A number of such species invading Australian ecosystems have been identified by Humphries *et al.* (22) whose findings are briefly summarised below.

On a continental scale, most major ecosystems have at least one serious invasive species. The exceptions are the alpine region, large tracts of rainforest or temperate forest, mangroves and the red sandy deserts of central Australia. With the exception of only a handful of species the exotic populations are expanding their range and infilling. Control programmes are currently effective only at a local scale although biological control efforts are under way for a few of the major problem species.

Broadscale infestations of single species covering hundreds of square kilometres are characteristic of northern inland Australia and reflect the gradual climatic gradients and the extensive rather than intensive land-use. The ecological effects of many of the species in question (such as prickly acacia, rubber vine, tamarisk, giant sensitive plant, buffel grass, and mission grass) has been the focus of this paper.

A patchwork of various infestations is more characteristic of southern and subcoastal Australia, reflecting greater spatial heterogeneity from steeper climatic and topographic gradients and the substantial fragmentation of the vegetation from intense development. In the tropics and the sub-tropics a host of vines and several highly invasive shrubs such as *Ligustrum*, are a particular threat for rainforest fragments which are vulnerable from the edges. Rainforest edges are also consistently at risk from fire fuelled by exotic grasses. The south-eastern coastal and subcoastal systems are being invaded by two subspecies of the highly invasive shrub *Chrysanthemoides monilifera* which forms virtual monocultures over large tracts of its habitat. The fragmented vegetation of the southern agro-pastoral belt is at risk from a range of species of grasses and herbs that are inhibiting recruitment of native species. Geophytes are invading some semi-natural areas in the southern states, Western Australia in particular.

Drainage lines, watercourses and associated habitats have the densest infestations of the locally prevailing exotic species and also tend to support a higher diversity of species. Consequently these highly restricted and ecologically critical habitats are at greatest risk. Wetlands in the tropics are being choked by the semi-aquatic grass *Brachiaria mutica*, and other ponded pasture species. Aquatic habitats remain at risk from a range of introduced exotic species, many from the aquarium trade. Outbreaks of water hyacinth and salvinia, *Salvinia molesta*, are a constant possibility, although these species are largely under control.

The seriousness of the smaller southern infestations is no less than those of the broadacre ones of the north. Relative to the size of the habitat available, these species can be viewed as incurring proportional damage. A social factor is also relevant in considerations of environmental impact. For example, urban bushlands are particularly vulnerable to weeds (22) and have a high percentage of naturalised species. The fragmented patches of natural vegetation remaining are socially among the most significant, given the proportion of the population that access them. The broadacre species, by contrast, are "out of sight, out of mind" but these are transforming continental scale areas, biologically rich or unique sites and some of the only biologically unexplored areas left in Australia. So the criteria for evaluating environmental impact change depending on geographic location and perception of priorities.

DISCUSSION

The total ecological impact of a weed is a function of the characteristics of the species, the characteristics of the host ecosystem and time. I distinguish this from its environmental impact only in as much as I would include social factors, which I touched on above, as part of total environmental impact.

The life-form of a species, that is, whether it is a grass, a vine or a tree, has a major bearing on its behaviour and impact as was implicit in the above descriptions. At a finer level of definition, its physiological, phenological, demographic and morphological attributes come into play to determine its relative competitiveness and its capacity to alter ecosystem-level processes. The prediction of invasiveness *per se* has traditionally occupied ecologists, but the current consensus is that general attributes are not reliable predictors of the potential weediness of a particular species in a particular system (32, 35, 29). Outcomes of colonisations will emerge only from focussed studies of particular invaders and particular target habitats.

Defining characteristics of an invasible system has also been a focus of theoretical ecology. (e.g. see 34 for a review). However, there is only one characteristic upon which I will concentrate on here: disturbance.

The patterns of success or failure among alien species are broadly associated with differences in land-use as well as with the physical environmental factors and the nature of the communities encountered (see 22 for a discussion for Australian conditions). There is overwhelming evidence that disturbance, particularly human disturbance, promotes plant invasions (see chapters by Hobbs and others in 8). Invading plants are almost wholly restricted to disturbed sites, especially sites altered by human activity.

The third factor in assessing impact is time. The current picture is only a snapshot of a dynamic process involving a number of time scales including those of the transforming processes (i.e. the feedbacks that follow alterations to the fire regime, nutrient cycling etc.), the spread of the introduced plant populations, and the intersection of events that causes an introduced species to become invasive.

The full impact of a species may not manifest until the population is large enough and the effect of modified processes becomes apparent. For example, the devastating geomorphological and hydrological effects of tamarisk in the USA are not apparent yet in the Australian situation because the invasion is still in its early stages and relatively small. The effects on reproduction of granivores of a nutritionally inferior food source may not become apparent for decades after the introduction of an exotic grass - an impact conjectured for buffel grass.

The potential habitat of most invasive species in Australia is not filled, and on a continent scale invasions continue to spread. Current control efforts may be slowing the rate of spread but not arresting it. The climatic limits of several of the most destructive species have been estimated and it is clear that they currently occupy only a fraction of their potential range. For example, *Mimosa pigra*, is now in the region around Darwin but suitable habitats occur across far northern Australia. Similarly rubber vine could spread from Queensland across the monsoonal semi-arid of the Northern Territory and Western Australia. There are many more examples (22). Moreover, species that are here but have not yet become invasive will manifest over time. Experience has shown that it may take decades to a century after introduction for a species to become highly invasive (20). The change from little spread to exponential spread is often sudden. Sometimes the changeover can be correlated with an episodic climatic event such e.g. *Tamarix aphylla* (14) or with a genetic mutation such as that documented for *Spartina* spp (40). The underlying causes of this time lag are complex and poorly understood, involving dispersal to a suitable habitat and with some species, genetic diversification (15). So called 'sleepers' are inevitable and many have been identified for Australia (22).

The unavoidable prognosis is that the impact of weeds on the Australian continent will continue to increase in terms of proportion of habitat invaded, the numbers of invaders present and ecosystem-level effects now latent or undetected.

This brings me to my final point.

I am of the opinion that there is a serious mismatch between the conservation significance of invasions and the effort ecologists have devoted to their study. In part this is due to the relatively recent awareness of the magnitude and seriousness of the process. With the SCOPE studies (16) there has been increasing level of interest in the study of natural systems invasions in Australia and a recent overview of the status of environmental weeds in the Australian landscape by Humphries *et al.* (22) has further focussed attention on this issue. Traditionally ecologists have preferred to study native organisms and have used exotics to clarify and build ecological theory on population and community dynamics. Until very recently, management related research has been limited to specific studies which underpin direct chemical, mechanical or biological control strategies, a legacy of agricultural weed control.

The same is true elsewhere. Temple (39) in an editorial for Conservation Biology writes that exotic organisms should be a high priority subject for research but they are not. The reasons he puts forward include misconceptions about the nature and magnitude of the problem and that threats posed by exotics are often understated and dismissed.

I wish to highlight two management related areas of research which need augmentation: the invasion-disturbance link and better documentation of impacts.

I believe that elucidating the relationships between an invasion and the underlying disturbance is the most important area of environmental weed research. To me it is a central tenet of long-term management that we need to manage the disturbance which makes the site invasible. Linkages between a plant's introduction, its establishment, survival and spread need to be examined in relation to specific human activities which may promote each successive stage of the process. We need to know, for key problem species or areas, the role in this process of activities such as grazing, fertilisation, manipulation of fire, transport or vegetation fragmentation. By defining the disturbance-invasion link more precisely, (ideally, quantitatively), opportunities for mitigating practices may emerge.

I have already alluded to the fact that only a small handful of studies have attempted to described a wide range of ecological effects accompanying the invasion process in Australia (e.g. studies on *Mimosa pigra*, 6, 27 and on *Tamarix aphylla*, 14). Most studies are partial (e.g. specific plant-plant interactions) and qualitative, and although they are useful in recording the phenomen or in providing insight into some aspect of the invasion, they do not provide comprehensive documentation of the process or its effects.

Quantitative or systematic documentation of ecosystem-level effects is essential for providing scientific rather than anecdotal evidence of impact. The management of weeds is dependent on public sector funding and integrated, supportive political, administrative and legislative frameworks. Although of itself not always enough, the weight of scientific evidence has to be there for political support of long-term effort in this area, for addressing conflicting land management practices, and for initiating early action weed management is not a short-term activity. As we know, the problem is ongoing and growing in magnitude. A comprehensive description of the nature, scope and dynamics of ecosystem-level effects of weeds provides the credible evidence upon which resources can be attracted for management. Such in depth, albeit descriptive studies, will undoubtedly also uncover important directions for management and contribute valuable data to ecological theory.

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MON 13200 - A NEW PRE-EMERGENT HERBICIDE FOR WEED CONTROL IN SUGAR CANE

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Summary. Pre-emergent applications of MON 13200 (thiazopyr) provided commercially acceptable control of a range of annual and perennial grass weeds in sugar cane including summer grass, *Digitaria ciliaris*, barnyard grass, crowsfoot grass, green summer grass, *Brachiaria subquadripara* and Guinea grass with rates of 0.5 kgai/ha providing 93, 88, 94, 89 and 96% control respectively. Control of certain broad-leaved weeds including bluetop, pigweed, *Portulaca oleracea*, blackberry nightshade, *Solanum americanum*, black pigweed and Star of Bethlehem was also demonstrated. Good crop safety was exhibited at rates of application up to 0.5kg/ha MON 13200.

INTRODUCTION

The herbicide MON 13200 (Methyl 2-difluoromethyl-4-isobutyl-5-(4,5-dihydro-2-thiazolyl)-6-trifluormethyl-3-pyridinecarboxylate) is a discovery of the Monsanto Company, USA. MON 13200 belongs to the pyridine chemical family and exhibits high unit pre-emergent activity against a range of grasses as well as certain small seeded broadleaf plants (1).

The primary mode of action of MON 13200 is the inhibition of cell division resulting from the disruption of microtubule formation (1). Seed germination is not inhibited by MON 13200 but subsequent plant development does not proceed normally.

Selectivity is exhibited in a range of annual and perennial crops including tree crops, vines, cotton, lucerne, peanuts, sunflowers and sugar cane. Thiazopyr is currently registered in a range of crops in Spain and South Africa.

Infestations of annual grass weeds in Australian sugar cane are a significant constraint to production in Australian sugar cane. Experimental work carried out by Chapman (3) in the Mackay district during the 1960's demonstrated that a severe infestation of *Echinochloa spp.* reduced plant cane yield by 12 tonnes/hectare. In a series of five experiments established in the Mackay and Tully districts over the 1985 and 1986 seasons, grass weed competition reduced ratoon cane yields from 7 to 30% (4). A loss of 7% yield on a crop having a potential of 80 tonnes/ha and a value of $25/tonne represents an economic loss of $140/ha. In the experiments referred to above, weeds exerted a significant competitive effect on yield until the top visible dewlap of cane reached 10-12 cm high (4).

Green cane trash-blanketing methods of production have had a major effect in reducing the impact of grass weed infestations in ratoon cane in the northern cane growing districts of Australia. However, the need for effective control of grasses in plant cane and in traditionally cultivated ratoon cane remains. A range of pre-emergent herbicides are available to growers including diuron, atrazine, ametryn, ametryn plus atrazine, metolachlor plus atrazine, trifluralin, pendimethalin, hexazinone plus diuron (5) though the directed application of the knockdown herbicide paraquat is commonly an integral part of in-crop weed control programmes.

The purpose of the experiments reported here was to evaluate the experimental herbicide MON 13200 for the pre-emergent control of annual grass and broad-leaved weeds in sugar cane compared to the commercial standard of atrazine plus ametryn. A second objective was to assess selectivity of treatments in both plant and ratoon cane.

METHODS

In all experiments reported here an emulsifiable concentrate formulation containing either 360 (MON 13232) or 240 g/L (MON 13211) active ingredient was used.

Efficacy experiments were established in commercial stands of plant or ratoon cane and subject to normal management practices up to the point of treatment application. Herbicide treatments were applied post-emergent to cane and pre-emergent to weeds (except where paraquat was added at 0.2 kg a.i./ha for control of emerged grass weeds in experiments 2, 9, 15 and 21) using a compressed gas sprayer equipped with flat fan (broadcast treatments) or flood jet (directed treatments) calibrated to deliver 80 to 120 L/ha with an operating pressure of 150 (directed) or 250 kPa (broadcast). Directed applications were used where cane exceeded approximately 80 cm in height (Experiments 2 and 15). Treatments were arranged in a randomised complete block design with three replicates. Plot size was 3 by 10 or 12 m. Site details for the efficacy experiments are summarised in Table 1.

Table 1. Site details for efficacy experiments in sugar cane

Expt. #	Location	Situation	Cane stage/height	Soil type
1	Woombye	plant (Q137)	pre-emergent	sandy clay loam
2	Yandina	ratoon (NC0-310)	out-of-hand; 140-180 cm	clay loam
3	Bundaberg	plant (H56-752)		grey forest soil
4	Yandina	plant (CP44-101)	pre-emergent	red podzolic
5	Tumbulgum	plant (Florida)	spike; 0-20 cm	river alluvial
6	Bingera	plant (Q145)	2-3 leaf; 10-40 cm	grey forest soil
7	Bingera	plant (Q145)	1-3 leaf; 10-35 cm	grey forest soil
8	Nambour	plant (Q110)	1-2 leaf; 10-30 cm	humic gley
9	Nambour	plant (Q137)	spike; 10-20 cm	alluvial clay loam
10	Gargett	plant (Q121)	1-4 leaf; 15-30 cm	loam
11	Tully	plant (Q122)	pre-emergent	clay loam
12	Tully	ratoon (Q130)	2-5 leaf; 20-60 cm	clay loam
13	Nambour	plant (CP44-101)	2-4 leaf; 15-40 cm	clay loam
14	Mackay	plant (Q124)	1-3 leaf;	sandy clay loam
15	Mackay	ratoon (H56-752)	out-of-hand; 85-100 cm	sandy clay loam
16	Sarina	plant (Q124)	4-7 leaf; 50-80 cm	sandy loam
17	Walkerston	plant (Q136)	pre-emergent	clay loam
18	Gargett	plant	pre-emergent	sandy loam
19	Ayr	plant (Q117)	pre-emergent	clay loam
20	Walkerston	plant (H56-752)	spike-2 leaf; 8-35 cm	clay loam
21	Walkerston	ratoon (Q135)	1-3 leaf; 10-30 cm	sandy clay loam
22	Rosella	plant (Q124)	8-12 leaf; 60-120 cm	sandy loam

Weed control was assessed using subjective assessments of control by individual weed species using a 0-100 scale where 100 represents complete control. Initial assessments were completed at 21 to 35 days after initial treatment (where weed growth in untreated plots was present) and thereafter at 45 to 70 days after treatment. In some experiments weed density in the cane drill was assessed using four one quarter or one square metre quadrats per plot.

Crop effects were assessed using a subjective 0 to 100 scale where a value of 0 indicates no effect and 100, complete crop destruction.

RESULTS AND DISCUSSION

Efficacy. Weed control assessments for the major grass weeds evaluated are summarised in Tables 2-5. MON 13200 applied at 0.5 kg a.i./ha provided a weed control or percentage control rating of 85 or greater (judged to be commercially acceptable) for summer grass, barnyard grass, crowsfoot grass, green summer grass and guinea grass in 33 of 37 assessments completed in 22 experiments 28 to 97 days after treatment. In contrast, within the same data set,the standard treatment of 4 kg a.i./ha ametryn plus atrazine provided this level of control in 14 of 37 assessments.

Of the grass weeds, summer grass and guinea grass appeared most susceptible to MON 13200 with 15 of 15 and 4 of 4 ratings reaching a value of 85 or greater for these two species respectively. Ametryn plus atrazine treatments provided commercially acceptable control of summer grass in 5 of 15 experiments while this was not achieved in any experiment where guinea grass was present.

Table 2. Pre-emergent control of summer grass *Digitaria ciliaris* in sugar cane

Treatment	Rate kg/ha	Control rating (frequency distribution)			Mean
		<75	75-84	>84	
MON 13200	0.25	1	1	3	82.8
MON 13200	0.375	0	1	3	93.2
MON 13200	0.5	0	0	15	92.9
MON 13200	0.75	0	0	8	92.8
MON 13200	1.0	0	1	14	95.8
atrazine+ametryn	4.0	7	4	4	80.5

Table 3. Pre-emergent control of barnyard grass in sugar cane

Treatment	Rate kg/ha	Control rating (frequency distribution)			Mean
		<75	75-84	>84	
MON 13200	0.25	1	2	0	71.5
MON 13200	0.375	0	0	1	91.5
MON 13200	0.5	0	2	5	87.5
MON 13200	0.75	0	0	2	94.0
MON 13200	1.0	0	0	7	94.3
atrazine+ametryn	4.0	4	1	2	72.1

Table 4. Pre-emergent control of crowsfoot grass in sugar cane

Treatment	Rate kg/ha	Control rating (frequency distribution)			Mean
		<75	75-84	>84	
MON 13200	0.25	1	0	1	80.0
MON 13200	0.375	1	1	0	78.0
MON 13200	0.5	0	0	6	93.8
MON 13200	0.75	1	0	1	87.5
MON 13200	1.0	1	0	5	95.8
atrazine+ametryn	4.0	2	0	4	85.6

Table 5. Pre-emergent control of green summer grass *Brachiaria subquadripara*

Treatment	Rate kg/ha	Control rating (frequency distribution)			Mean
		<75	75-84	>84	
MON 13200	0.25	1	0	1	78.0
MON 13200	0.375	0	1	0	82.0
MON 13200	0.5	0	2	3	89.2
MON 13200	0.75	0	0	2	97.5
MON 13200	1.0	0	2	3	91.8
atrazine+ametryn	4.0	1	2	2	80.0

Table 6. Pre-emergent control of guinea grass in sugar cane

Treatment	Rate kg/ha	Control rating (frequency distribution)			Mean
		<75	75-84	>84	
MON 13200	0.25	0	0	2	96.0
MON 13200	0.375	0	0	2	92.0
MON 13200	0.5	0	0	4	96.3
MON 13200	0.75	0	0	2	98.0
MON 13200	1.0	0	0	4	100.0
atrazine+ametryn	4.0	2	2	0	73.6

Dry weather conditions following application occurred frequently in the course of the experiments reported here, with 9 of 22 experiments having an extended period (>4 weeks) during which no rainfall or irrigation occurred in the period following application. MON 13200 performed well under these conditions with good control of grass weeds. In contrast, the activity of the atrazine plus ametryn standard appeared to be adversely affected by these conditions. Large losses in activity of atrazine over 10 days following application to a black earth soil and protected from rainfall have also been observed in a series of four experiments conducted by Marley and Robinson (6). While the significance of photodecomposition and or volatalization of atrazine from the soil is not fully understood, available data indicate that both occur to some extent if high temperatures and prolonged sunlight follow application before precipitation (7).

Crop injury. Only slight growth reduction occurred in cane treated with rates up to and including 0.5 kg/ha MON 13200 except in one experiment (Table 7). Treatments in this experiment (experiment 19) were applied prior to crop emergence and immediately prior to flood irrigation. Soil surface crusting occurred following irrigation causing a reduction in crop emergence which was exacerbated by the presence of herbicide treatments and the withholding of normal cultivation. Significant and unacceptable crop injury (injury rating >19) occurred in a relatively small proportion of trials at rates of 1.0 kg/ha and above.

Injury was characterised by crop stunting and appeared to be enhanced where wet soil conditions prevailed soon after application. Effects are attributed to soil uptake rather than foliar as there were no evidence of leaf symptoms attributable to post-emergence applications to the crop.

Notwithstanding, crop effects except at three times or greater than the proposed rates of application appeared to be transitory. A further study is currently underway to assess this more comprehensively on a range of cane varieties using crop yield as the final criterion for injury.

Table 7. Sugar cane phytotoxicity (efficacy experiments)

Treatment	Rate kg/ha	Injury rating (frequency distribution)			Mean
		<11	11-19	>19	
MON 13200	0.25	5	0	0	5.33
MON 13200	0.375	7	1	0	2.08
MON 13200	0.5	22	3	0	4.44
MON 13200	0.75	12	2	0	4.04
MON 13200	1.0	19	4	2	5.01
MON 13200	1.5	3	1	1	12.66
MON 13200	2.0	1	1	3	16.66
atrazine+ametryn	4.0	24	1	0	3.05

Note: injury rating on a 0-100 scale where 0 = no effect and 100 = complete crop destruction.

MON 13200 would appear to provide a significant opportunity to canegrowers seeking to reduce reliance on in-crop weed control with cultivation or post-emergence herbicide treatments by opening up the window of application of pre-emergent herbicide treatments in advance of the onset of initial weed germination without significant loss of activity associated with delayed activation by rainfall or irrigation.

Pre-emergent herbicides currently available are generally used once irrigation or rainfall has stimulated weed emergence. Whilst this approach is successful if herbicide treatments are then applied to relatively small weeds, weather conditions may be such that timely application is not always possible and weed escapes occur particularly in the plant line where spray coverage may limit effectiveness. Nevertheless, MON 13200 will also be effective in combinations with knockdown treatments such as paraquat where weed emergence has occurred prior to treatment.

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OCCURRENCE OF THE RUST FUNGUS *UROMYCES RUMICIS*, A BIOLOGICAL CONTROL AGENT OF FIDDLE DOCK *(RUMEX PULCHER)* IN WESTERN AUSTRALIA

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Summary. A strain of the rust fungus *Uromyces rumicis,* is widely established as an unintentionally introduced biological control agent on field populations of *Rumex pulcher* in south-west Australia seemingly without attacking other Polygonaceae species. The extent to which the fungus may effect the health of *R. pulcher* populations is unknown.

INTRODUCTION

The rust fungus *Uromyces rumicis* has been reported from Europe and Africa on *Rumex* species in the subgenus *Rumex* and from the related Polygonaceae genus *Emex* (2, 6, 9) and has been long considered a potential biological control agent for these weeds (4, 6). It was first studied in Europe as a control agent for curly dock, *Rumex crispus*, in North America (4, 5). The rust is macrocyclic and heteroecious using *Ranunculus ficaria* as a host for the haplontic phase. The dikaryotic phase is host specific to *Emex* and *Rumex* subgenus *Rumex* (1, 5, 6) and the haplontic phase is specific to *Ranunculus ficaria* (9). The fungus has been proposed as a potential biological control agent for *Emex* and *Rumex* species in Australia (10).

Uromyces rumicis was first reported as an unintentional introduction to Perth, Western Australia, in 1986 (11). The fungus was observed on *R. crispus, R. pulcher* and *E. australis* grown in glasshouses and had not been located in the field. Here we report on its distribution and host range in the field in Western Australia.

METHODS

During 1990 - 1992 surveys were made of Polygonaceae throughout the agricultural regions of south-western Australia as part of an assessment of the presence of potential biological control agents. Identification of rust fungi was based on Wilson and Henderson (12), and identification of *Rumex* species on Rechinger (7).

RESULTS AND DISCUSSION

Uromyces rumicis was found on *R. pulcher* at 14 sites in south-west Western Australia. The sites were found west of the area bounded by Namban (30°23'S 116°03'E) in the north, Broomehill (33°51'S 117°38'E) inland and Albany (35°02'S 117°53'E) in the south. The area has over 600 mm annual rainfall.

The following plants and sites were examined during the survey: *E. australis* (31 sites), *E. spinosa* (5 sites), *R. crispus* (39 sites), *R. conglomeratus* (13 sites), *R. obtusifolius* (1 site) and *R. pulcher* (25 sites). Often two or three *Rumex* species were found at the same site yet only *R. pulcher* showed signs of attack. Uredia and telia were evident from the end of spring until plants senesced (November and December) and again in May when the plants produced rosettes.

The host of the haplontic phase, *Ranunculus ficaria*, is not known from Western Australia (3) so consequently was not included in the survey.

The impact of *U. rumicis* on *R. pulcher* has not been assessed, but may be important as indicated by studies on related species. Schubiger *et al.* (8) showed that *U. rumicis* caused severe damage to *R. crispus* grown in a glasshouse, reducing the number of leaves and causing a 55% reduction in dry weight of roots and leaves compared with controls. Less damage occurred to infected *R. obtusifolius* grown in a glasshouse. Inman (5) inoculated field plots of *R. crispus* and observed a lower seed weight and number in infected plants.

The phenology of the fungus in Western Australia indicate that strains adapted to cooler conditions would be more suitable for introduction into the Mediterranean climate of Western Australia. Secondly, the limited host range in Western Australia indicates that strains would have to be selected for each target species of *Rumex* or *Emex*. For example, a strain of the fungus from *E. australis* has been studied (6) and a strain from *R. crispus* has been proposed for introduction into North America (9).

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ARE PRE-EMERGENT WEED CONTROL AND ZERO TILLAGE COMPATIBLE IN REGIONS WITH LIMITED RAINFALL?

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Summary. Consistent performance of pre-emergent herbicides requires good incorporation by rainfall. Since rain is unreliable, mechanical incorporation is often needed, which is not desirable in zero-tillage systems. Conservation of soil moisture is imperative under semi-arid conditions, where planting and herbicide application is often carried out simultaneously using one implement. Crop phytotoxicity may occur from heavy rainfall on light soils immediately after application. Alternatively, poor weed control may result from insufficient rainfall after application, failing to incorporate the herbicides into the soil profile. These problems are discussed with weed control in sorghum as an example. The requirement for careful planning is highlighted.

INTRODUCTION

Water is considered the major limiting factor affecting yields in rain-fed grain growing in Queensland. Zero-tillage has several advantages under the semi-arid conditions of these regions: It conserves moisture, reduces erosion, uses less fuel and ensures more consistent yields (1). The benefits of zero-tillage require efficient weed control, which most often depends on the use of herbicides in addition to crop rotation.

Pre-emergence residual herbicides are a cost-effective tool for ensuring ideal growing conditions for the crop. Consistent performance of pre-emergence herbicides requires good incorporation by rainfall. Since rain is unreliable, herbicide application behind the planter may result in poor weed control due to lack of incorporation. Alternatively, crop phytotoxicity may occur from heavy rainfall on light soils immediately after application. Volatile formulations are also unsuitable for zero-tillage, since they require mechanical incorporation.

Several problems are associated with pre-emergence herbicide use in zero-tillage cropping systems:

- poor results if no rain follows after the planting rain;
- reduced efficacy because of heavy stubble; and
- lack of flexibility, i.e. no "opportunity cropping" due to concern over herbicide residues in crop rotation.

Therefore, post-emergent weed control is often seen as the answer to these problems. However, careful planning on an individual paddock basis, together with early pre-plant herbicide application, is a recipe for a long-term, successful approach to weed control in a sustainable zero-tillage broad-acre cropping system. This shall be demonstrated with sorghum in a summer/winter crop rotation as an example (reasonable rainfall, e.g. Darling Downs region).

CROP ROTATIONS

By following a crop rotation, carefully planned for each paddock (Table 1), it can be decided in advance, which crop will be planted and what preparation is needed. Although climatic conditions may render some adjustments necessary, long-term success will rely on adherence to the plan.

Table 1. Winter Summer Crop Rotation.
Summer crops: Sorghum, Maize, Sunflower;
Winter crops: Wheat, Barley, Canary, Canola, Linseed.
OC: "Opportunity" Crop; Mungbean, Chickpea, Millet, Panicum.
Shaded areas: Possible use of atrazine for weed control.

Paddock	1	2	3	4	5
1st year	Fallow/OC	Fallow/OC	Summer		Summer
	Winter	Fallow/OC	Fallow/OC	Winter	
2nd year		Summer	Fallow/OC	Fallow/OC	Summer
	Winter		Winter	Fallow/OC	Fallow/OC
3rd year	Fallow/OC	Summer		Summer	Fallow/OC
	Fallow/OC	Fallow/OC	Winter		Winter
4th year	Summer	Fallow/OC	Fallow/OC	Summer	
		Winter	Fallow/OC	Fallow/OC	Winter
5th year	Summer		Summer	Fallow/OC	Fallow/OC
	Fallow/OC	Winter		Winter	Fallow/OC

In the case of a summer crop, sorghum is the most likely option, and atrazine the preferred pre-emergence herbicide. Since planting is preceded by a fallow period, it is best if atrazine is applied to the fallow in autumn/winter (April-July) at a rate of 1.8 kg a.i./ha to 3.25 kg a.i./ha, depending on weed pressure and crop rotation.

This will control weed growth in the fallow, and if weed pressure is low, no further herbicide will be needed. The low temperatures prevailing during this period will result in little loss of activity if incorporating rains fail. Alternatively, an early pre-plant application will achieve similar results, provided that it occurs before temperatures reach above 30 degrees C. If there is a high grass pressure, metolachlor may be used at planting with Concep II treated seed, or a proprietary mixture of atrazine + metolachlor. However, the latter option should only be used when rainfall is certain to occur within 10 days. The very early application has several benefits: It helps preserve moisture by controlling weeds germinating during the fallow, the chances of weed control failure are minimised, and plant back restrictions are avoided. The avoidance of atrazine residues is extremely important, as is demonstrated by ongoing research at the Queensland Department of Primary Industries (S. Walker, personal communication). A potential disadvantage of residual herbicides may be a negative effect on mycorrhiza, which should be a focus of further research.

CONCLUSION

This example shows that the use of pre-emergent residual herbicides is a valuable tool in zero-tillage broad-acre cropping. Planning for crop rotation and herbicide use should be on a paddock by paddock basis, allowing maximum flexibility. Growers who commit themselves to zero-tillage are also committed to long-term, sustainable farming, and therefore include planning for herbicide use, enabling minimal reliance on herbicides for weed control.

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INTEGRATED CONTROL OF THE SHRUB *DODONAEA ATTENUATA* BASED ON GOAT GRAZING AND HERBICIDE APPLICATION

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Summary. The use of goats to control the woody weed hopbush (*Dodonaea attenuata*) resulted in a shrub mortality of 70%, with their impact being greatest in years of low rainfall and low pasture biomass. After goat destocking and a period of high rainfall, some shrub regeneration occurred. Applications of four rates of glyphosate (Roundup®) to regrowth resulted in an apparent mortality of 66% of all shrubs sprayed at the highest rate. Partial budgeting analysis revealed that under the goat stocking treatment the sheep stocking rate would need to increase twofold for one year or by one fifth for ten years to pay for the displacement of sheep alone, costing at least \$3.83/ha. It is unlikely that sheep stocking rates could be increased to the amount required to meet either these costs or the \$20.02/ha associated with herbicide treatment.

INTRODUCTION

Woody weed infestation is clearly recognised as one of the most serious problems encountered by landholders in much of Australia's semi arid rangelands. Farm profitability is reduced by woody weed proliferation through increased costs of production and reduced livestock production (4). Heavy infestations can reduce gross margins by as much as 50% compared to relatively open country (1). The low productivity of infested areas dictates that, to be cost effective, management options to control these weeds be of low cost and produce lasting benefits.

Of the management options available, fire is generally seen as the most cost-effective. However, disadvantages are the income forgone when an area is destocked after a fire, low mortality rates for some woody weed species (e.g. *Eremophila* spp.) and impracticality in dense populations due to restricted fuel production. As an alternative, mechanical control (e.g. blade ploughing), is expensive and may also promote seedling regeneration in some species as a result of soil disturbance. However, in areas of dense infestation, pasture biomass is usually low, restricting the opportunity to burn and rendering the cost of mechanical or herbicide treatments prohibitive. This paper describes the defoliation response of hopbush to different concentrations of the herbicide Roundup® following goat grazing on sandy red earths north west of Cobar, and the associated costs of using this control strategy.

METHODS

Four 50 ha paddocks were grazed with goats for three years from June 1988 to June 1991. High goat stocking rates were separated by two destocking events (Table 1). This strategy resulted in an average stocking rate of 1.5 goats/ha/month.

Under the goat stocking treatment six transects (4 m x 100 m) were located in each of the four paddocks. The first 25 shrubs along each transect were monitored on 8 occasions at approximately 6 monthly intervals. Damage and reshooting categories were recorded for each shrub, but the results reported here are for shrubs assessed as dead or no leaves present.

Table 1. Goat grazing treatment and pasture biomass levels at the end of each stocking period commencing June 1988 and ending April 1991.

Stocking rate (/ha)	Stocking period (months)	Pasture biomass (kg/ha)
0.4	18	294
4	11	33
spelling	4	68
1	2	<10

From August 1988 pasture biomass was assessed in each paddock at approximately three monthly intervals and at destocking events using a comparative yield technique (5). At each, destocking exclosures were built to simulate the permanent removal of goats and to allow shrubs to re-shoot. The herbicide Roundup CT® (450 g/L glyphosate) was applied at 0%, 12%, 24%, 50% and 100% of the manufacturers recommended rate for blackberry control (1 L/100 L) with the wetting agent, BS1000 (200 mL/1000 mL) in mid July 1992. Treatments were randomised within 2 stocking histories (12 and 20 months regrowth) on two land-types (dune and swale) within four exclosures built in each paddock. Plants were sprayed in 2 x 30 m sweeps using an Ag-merf® gas gun powered by propane gas. Biomass of individual shrubs was estimated using a double sampling technique on five occasions; prior to herbicide application, and 40, 90, 137 and 175 days after treatment application.

Analyses of variance were used to examine the effect treatment, stocking history and land-type on shrub biomass using initial biomass as a covariate. Analyses were performed using the statistical package SAS (6). Type III sums of squares (3) were used where the sums of squares for each main effect and interaction is adjusted for all other terms. A separate analysis was performed for day 175 where the shrubs were designated as dead (zero biomass) or alive (non-zero biomass). The proportion of surviving plants was employed as the dependent variable (an arc sin transformation being used to stabilise the variable). Average initial biomass was used as a covariate. Models were restricted to main effects, covariates and first-order interactions and least square means (+/- standard error) were estimated for each main effect and interactions. Discounted partial budgeting was used to identify the net present value of each control strategy.

RESULTS AND DISCUSSION

A 70% shrub mortality was observed under our goat grazing treatment (Fig. 1a), goats being most effective at pasture biomass levels below 100 kg/ha (Fig. 1b). Considerable gains could result from this reduction in shrub foliage such as improved visibility for easier mustering and the reduction in shrub canopy (which would limit shrub seed production and thereby encourage future pasture production). However, some heavily defoliated shrubs resprouted when goats were removed, suggesting that the duration of grazing was not sufficient to achieve shrub mortality. A further understanding of the response of shrubs to the frequency, duration and intensity of defoliation, over a range of seasonal conditions would be integral to the development of an effective goat stocking strategy.

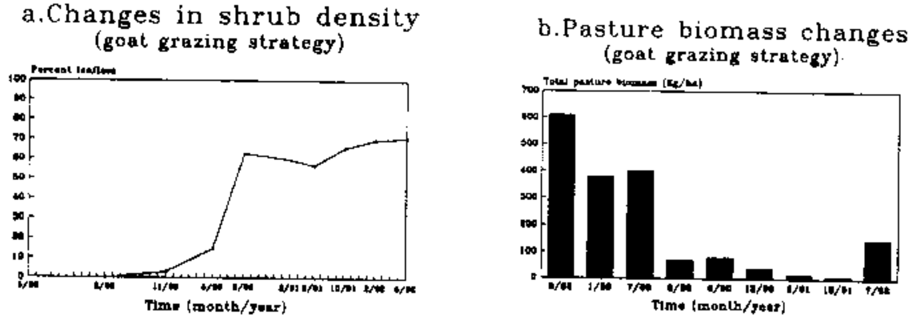

Figure 1. Changes in shrub density as a result of goat grazing (a) and associated pasture levels (b).

The costs associated with this goat stocking treatment are shown in Table 2. Under our grazing treatment the sheep stocking rate would need to increase twofold for one year, by one third for 5 years or by one fifth for ten years to pay for the cost of destocking alone (not including the costs of fencing). To include the costs of fencing the sheep, stocking rate would need to be increased by at least 50% over a ten year period.

Table 2. Costs associated with the goat grazing treatment and increases in stocking rate needed to recover costs.

	Cost $/ha	1 year*	5 years*	10 years*
		extra dse/ha		
with fencing				
100 ha	73.69	10.66	2.13	1.07
1,000 ha	25.92	3.75	0.75	0.38
10,000 ha	10.82	1.57	0.31	0.16
without fencing	3.83	0.55	0.11	0.06

* increase in sheep stocking rate required to pay for cost of goat treatment over a specified time.

Initial observations on a follow-up chemical application to coppicing shrubs suggest potentially good mortality rates can be achieved at higher rates of application (Fig. 2a). Despite favourable growing conditions after herbicide application (Fig. 2b), six months after a winter application of

Glyphosate, 66% of all shrubs sprayed at the highest rate had no leafy biomass These results contrast to unsprayed shrubs where biomass increased by almost 50% over the same period. Actual shrub mortality will be confirmed by monitoring these shrubs for the next 12 months.

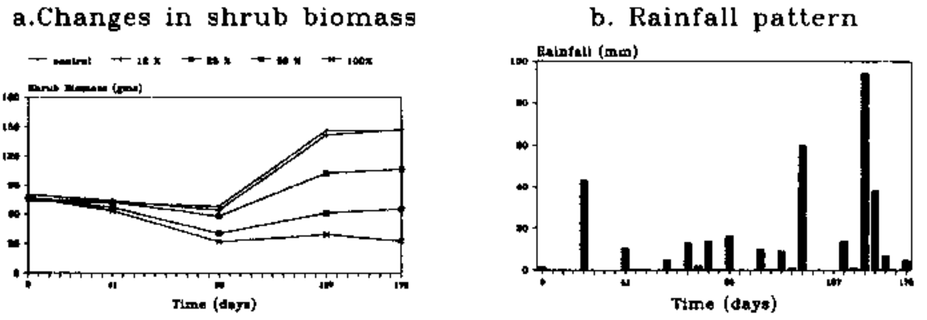

Figure 2. Changes in shrub biomass under different glyphosate rates (a) and rainfall during herbicide treatment (b).

Winter application of glyphosate did not reduce the shrub's susceptibility to this chemical, similar to the results reported by Toft (9) for *Mimosa pigra*. Age of regrowth did not significantly affect shrub biomass at anytime after chemical application, despite older shrubs having an initial higher biomass (113.0 g $\pm$ 10.39) than younger growth (80.2 g $\pm$ 10.39). At the higher rates of glyphosate the effect of the chemical tended to have a more rapid effect on older shrub regrowth, a result expected as presumably the more actively growing younger regrowth would have a higher chemical tolerance. While shrubs inhabiting the low lying swales always tended to have a greater biomass than those on top of dunes, land-type did not significantly influence the effects of herbicide, suggesting that position within the landscape will not influence this species response to this type of chemical application.

It is unlikely the stocking rates could be increased by the amounts needed to pay back the costs for herbicide treatment. If it is assumed that the stocking rates will be reduced by the amounts indicated in Table 3. This may provide economic justification for this treatment.

An increase in income would be expected as stocking rate increases with the removal of woody weeds. However recovering costs associated with this integrated control strategy are unlikely as stocking rate would have to double over the first five years. It is unlikely that such an increase in stocking rate would result in a sustainable grazing system. Whilst this type of control strategy is expensive, undertaking no shrub control is likely to result in a further decline in stocking rate and subsequent productivity. For this reason and from a national environmental perspective, public may need to decide whether they can support or provide financial assistance for woody weed control in the Western Division.

Table 3. Costs associated with herbicide treatment and increases in stocking rate needed to recover costs.

Glyphosate Rate	Cost/ha ($)	1 year *	5 years *	10 years *
			extra dse/ha	
12%	9.46	1.37	0.27	0.14
25%	11.02	1.59	0.32	0.16
50%	14.02	2.03	0.41	0.20
100%	20.02	2.90	0.58	0.29

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A REVIEW OF QUEENSLAND DEPARTMENT OF LANDS RESEARCH ON BIOLOGICAL CONTROL OF WEEDS

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Summary. Queensland Department of Lands has imported and released potential biological control agents on twelve weeds. We review these projects and highlight some critical issues including relative success of collections from the same versus related plant taxa, host specificity criteria, number of agents required and assessment of efficacy of control agents. Control of the harrisia cactus complex, *Eriocereus spp.*, by a mealybug has been clearly successful. Results of insect releases on herbaceous and woody weeds are less clear. Partial control of seven weed species has been achieved, with effects ranging from major reductions in density over the range of the weed to temporally or spatially scattered damage. Projects on four weeds have achieved no significant control to date.

INTRODUCTION

The highly successful biological control campaign against prickly pear, *Opuntia stricta*, involving *Cactoblastis cactorum* set the stage in Queensland for continuing research into this method of weed control. When the Commonwealth Prickly Pear Board was terminated in 1939, Queensland Department of Lands took over responsibility for control of exotic weeds. Research into biological control, and other methods of weed control, is carried out at the Alan Fletcher Research Station in Brisbane and at the Tropical Weeds Research Centre at Charters Towers in north Queensland.

The current status of Department of Lands biological control projects is reviewed in this paper. The relevance of these projects to the debate of some critical issues in biological control is discussed.

STATUS OF PROJECTS

The success of biological control projects was assessed by the extent to which previously used control measures, such as herbicides or mechanical control, have been replaced or reduced following the release of biological control agents. The status of projects on twelve weeds for which agents have been released is summarised in Table 1.

Harrisia cactus is a weed of grazing lands in central Queensland. The mealybug has greatly reduced density of the cactus, but the insect has limited powers of dispersal. Control by government and landholders by mechanical clearing and herbicide application has been replaced by distribution of the mealybug (12).

Noogoora burr is a weed of grazing lands throughout much of Queensland, reducing pasture growth, impeding access to water, and contaminating wool with burrs. Following the apparently accidental introduction of a rust fungus, noogoora burr is no longer considered a serious weed by many graziers and the cost of removal of vegetable matter from wool has been greatly reduced (2).

Table 1. Current status of Queensland Department of Lands biological control projects against weeds

Weed	Degree of control	Effective agents
Eriocereus spp harrisia cactus	acceptable	*Hypogeococcus pungens* mealybug
Xanthium strumarium noogoora burr	acceptable, many areas and seasons	*Puccinia xanthii* rust fungus
Mimosa invisa giant sensitive plant	acceptable, many areas and seasons	*Heteropsylla spinulosa* sap-sucking bug
Baccharis halimifolia groundsel bush	partial, inadequate	*Oidaematophorus balanotes* stem-boring moth *Megacyllene mellyi* stem-boring beetle
Lantana camara lantana	partial, some areas and seasons, inadequate	*Teleonemia scrupulosa* sap-sucking bug *Octotoma scabripennis*, *Uroplata girardi* leaf-mining beetles *Phenococcus parvus* mealybug
Parthenium hysterophorus parthenium	partial, inadequate	*Epiblema strenuana* stem-galling moth
Ambrosia artemisiifolia annual ragweed	partial, inadequate	*Epiblema strenuana* stem-galling moth
Ageratina adenophora crofton weed	partial, inadequate	*Cercospora eupatorii* leaf-spot fungus
Ageratina riparia mistflower	none	—
Cryptostegia grandiflora rubber vine	none	—
Acacia nilotica prickly acacia	none	—
Parkinsonia aculeata parkinsonia	none	—

Giant sensitive plant, *Mimosa invisa*, is a fast growing, prolific weed of pastures, crops, plantations and roadsides in the wet tropics. Thorny clumps prevent grazing and restrict access. Control with herbicides continues in crops. Herbicide use by graziers and government has been drastically reduced since introduction of the psyllid in 1988/89, except for areas and seasons that are too wet or too dry for the psyllid.

Biological control agents inflict damage that is believed to significantly reduce vigour of individual plants and, in some cases, populations of five of the weeds listed in Table 1, but without apparently reducing the need for alternative methods of control. This degree of control is listed as partial but unacceptable.

Four biological control targets for which only one or two agents have been released remain unaffected (Table 1).

CRITICAL ISSUES IN BIOLOGICAL CONTROL

Some theoretical aspects of biological control are raised in many of the forums in which biocontrol is discussed. The continuing discussion indicates that these issues are unresolved, and some perhaps cannot be resolved to the stage that useful generalisations can be made. Four of these issues are discussed below in the light of evidence provided by examples of weed biocontrol in Queensland.

<u>How many agents should be released</u>? Myers (9) has challenged the "conventional wisdom that more insect herbivory is better for weed control" to conclude that success is more frequently achieved by a single species.

In each of the cases of successful control listed in Table 1, success has been achieved by a single species following release of between two, for giant sensitive plant, and five, for noogoora burr, agents. Twenty five species have been released on lantana, with four inflicting some damage, and eight have been released on groundsel bush, with two inflicting some damage, and in both cases only partial, inadequate control has been achieved. These examples support Myers' (9) suggestion that each introduction is a lottery that may or may not achieve success, and that more established agents may not improve control.

<u>Efficacy of "old" versus "new" associations</u>. Hokkanen and Pimentel (8) concluded that biocontrol agents collected from species other than the target, thus a new association, have been more successful than agents collected from the target species, an old association. Goeden and Kok (6) refuted this claim for weed biocontrol, citing groundsel bush as an example but without access to complete data. Data for all species tested, presented in Table 2, provides further support for the conclusion of Goeden and Kok that new host-plant incompatability is a major obstacle for new associations in weed biocontrol.

<u>Assessment of efficacy of agents.</u> Harris (7) suggested that economic evaluation of weed biocontrol is necessary to ensure continued funding, and that scientific evaluation is necessary to develop concepts that will lead to increasing success in weed biocontrol.

The first of Harris' (7) points is increasingly important as funding for science in general and weed biocontrol in particular becomes more competitive. Evaluations of harrisia cactus (12) and noogoora burr (2) have clearly demonstrated the large benefits accruing from successful weed biocontrol. Evaluation of the partial control of parthenium attributed to the stem-galling moth would identify any economic advantage attributable to effects on parthenium that allow pastures to compete more successfully with the weed. However, the resources necessary to do the evaluation may be better directed towards introduction of further agents.

Table 2. Comparison of efficacy of old and new associations for biocontrol of *Baccharis halimifolia*

	Old associations	New associations
Collected from:	*Baccharis halimifolia*	Other *Baccharis sp.*
Number of species:		
tested	7	14
successfully reared on *B. halimifolia*	5	3
released in the field	5	3
established in the field	4	2
effective	1	1

Harris' (7) second point is appealing to scientists, but can it be supported? Evaluation has allowed modification of the weed-biocontrol agent system under study to increase success of that system (14), but most attempts at generalisation have failed (4). As Cullen (4) suggests, scientific evaluation must be directed towards consideration of the particular insect-plant interaction.

Host specificity criteria. The centrifugal phylogenetic method of host specificity testing (13) has been adopted in Australia. These tests have been successful in excluding potentially significant pests and identifying potential for attack on non-target native plants (10). However, these tests are time consuming and may indicate an artificially wide host range (5).

The rust on noogoora burr and the mealybug on lantana (Table 1) were apparently accidental introductions. Given the results of subsequent host testing of these agents (1, 11), formal approval for release probably would not have been granted. The host ranges of these agents in the field are largely restricted to the weed hosts, providing further evidence that decisions based on the usual tests may be too conservative.

Greater reliance should be placed on the host range of potential agents in the field in their country of origin, and Cullen's (3) suggestions for increasing realism of test procedures should be adopted.

CONCLUSIONS

This review of successes and failures in weed biological control by Queensland Department of Lands provides further data relevant to debates over some critical issues in the weed biocontrol process. Whether science can make major contributions to what is still essentially an empirical process remains to be seen.

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CONSTRAINTS TO THE INTRODUCTION OF BIOCONTROL AGENTS FOR PRICKLY ACACIA (*ACACIA NILOTICA*)

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Summary. Prickly Acacia, *Acacia nilotica*, is attacked by over ninety different species of insect in Kenya. However, only a small number of species appear to fulfil the necessary criteria for biocontrol being both adequately specific and potentially damaging. I suggest that the gall midges are potentially the most damaging insect group and extensive field survey work in Kenya indicates the midges are host specific. However, the requirement of the Australian Quarantine and Inspection Service that potential agents must be tested against a long list of plant species makes testing of these insects, which are very short lived and dependent on developing buds and flowers difficult. This is particularly so for prickly acacia as it has not proven possible to get this weed and many related species to flower and pod in pots.

INTRODUCTION

Prickly acacia, *Acacia nilotica*, is an exotic species which was deliberately introduced into Queensland in the 1920s and 1930s and promoted as a shade and fodder tree. Although prickly acacia trees are still considered beneficial at low densities in some situations, undesirable thickets develop from the enormous soil seed bank after years of above average rainfall. Prickly acacia is particularly a problem on the fertile black soils of the Mitchell Grass Downs (1, 2). Approximately 7 million hectares of a total of 22 million hectares of the Mitchell Grass Downs are currently infested with prickly acacia (27). It is predicted that given a series of wet years, the entire Downs region could be lost to prickly acacia thorn forest resulting in increased soil erosion and a much reduced carrying capacity (27).

A five year biological control program based in Pakistan was initiated in 1980 and resulted in the introduction of two insects, a seed-feeding bruchid and a shoot-boring moth (20). Only the bruchid, *Bruchidius sahlbergi* Schilsky, has established. It is now widespread destroying up to 50% of prickly acacia seeds. However, the bruchid appears to be having a minimal impact on the spread of prickly acacia.

A three year biological control project was initiated in Kenya in 1989. I was based at Muguga, near Nairobi, for the project. Ninety-one different species of insect were found attacking prickly acacia in Kenya. However, only a few of these species appear to have potential for biocontrol. Potential insect biological control agents must fulfil two different criteria: they must be adequately host specific and they must be potentially damaging. From these perspectives prickly acacia presents perhaps more challenges for biocontrol than "the average weed".

Prickly acacia is very closely related to much of the Australian flora. There are three subgenera of Acacia. Most phyllodinous Australian species are in the subgenus Heterophyllum. Many, principally African species, are in the subgenus Aculeiferum. Prickly acacia and two native Australian species, *Acacia bidwilli* and *Acacia sutherlandii* and one naturalized Australian species considered a beneficial, *Acacia farnesiana*, belong to the subgenus Acacia. The above three Australian members of the subgenus Acacia also occur on the Mitchell Grass Downs. A very high level of host specificity, perhaps at the level of species specificity, is thus required of potential control agents. However, if great biological control potential can be demonstrated, insects which also feed on the three Australian acacias in the same subgenera might be considered for introduction. Harris (9) and Cullen (4) discuss the risks associated with releasing control agents capable of feeding on native plant species and generally conclude that damage is unlikely to be significant.

Also, particular problems are presented by prickly acacia being a tree. Amongst other difficulties, potted prickly acacia and related tree species usually do not flower or pod, which makes testing (which must be undertaken in quarantine) and mass rearing of insects dependent on developing flowers and pods, impractical at the present time. We are currently experimenting to overcome this problem. An additional consideration with prickly acacia is the presence of nine recognized subspecies with different geographic ranges in Asia and Africa. The weed in Queensland is considered to be *A. nilotica indica*, native to the Indian subcontinent. *A. nilotica leiocarpa* and *A. nilotica subalata* are the two subspecies native to Kenya and the subspecies from which the insects discussed in this report were collected.

I will now discuss the five groups of insects found in Kenya which appear to have most potential for biocontrol and outline the present position with these insects with particular reference to their level of host specificity and potential to damage prickly acacia. The insects are discussed in what I consider to be an ascending order of potential for biocontrol. However, my attempts at grouping and prioritizing should be understood in the context that biocontrol remains in many ways as much art as science (5,26). It has in the past proven impossible to predict which insect species will be most effective.

An additional limitation of the following study, and of relevance to all biocontrol work, is increasing evidence for the prevalence of cryptic (also known as sibling) species (22). Should we dismiss insects as inadequately host specific on the advice of taxonomists using morphological characters? For example, cryptic species are very common in scale insects were morphological conservatism appears to be a widespread phenomenon (18). I only tested four of the eight species of scale insect mentioned in this report, the remaining four were rejected on the advice of taxonomists who indicated they were cosmopolitan and polyphagous.

RESULTS AND DISCUSSION

Flower-feeding lepidoptera. The flowers of acacias in Kenya are almost exclusively utilized by lepidoptera (15). I reared forty-three different species of lepidoptera from the inflorescences of twenty-six different species of Kenyan acacia over a two year period (15). Field survey data indicated that no species of lepidoptera is specific to prickly acacia but most appeared restricted to the subgenera *Acacia* and *Aculieferum*.

If these flower-feeding insects were likely to be very damaging to prickly acacia, feeding on the three Australian species in the subgenus Acacia might be tolerated (see 17 for a precedence). However, given that over 99% of the flowers produced by prickly acacia are normally aborted (25) I suggest an unrealistically large percentage of flowers would need to be destroyed for the lepidoptera to have any impact on seed production. In addition, dissection of inflorescences in Kenya suggested that most lepidopteran larvae do not destroy all flowers in an inflorescence before moving on to the next inflorescence (Marohasy & Hongo, unpublished data).

It would thus appear this group of insects have limited potential for the biological control of prickly acacia, being inadequately host specific and unlikely to be damaging.

Seed-feeding insects. I found a diverse complex of insects attacking the pods and seeds of prickly acacia in Kenya including: externally feeding hemiptera; lepidoptera and hymenoptera which feed internally on green seeds; lepidoptera which feed internally on mature seeds; and bruchids and a cerambycid which feed internally on mature seeds (15). Field survey data and literature records indicate that many of the lepidoptera and hemiptera are pest species (15). Most of the bruchids and cerambycids appeared restricted to the acacias but field data for many of the species, and host specificity testing of two species, indicates they are also capable of feeding on the seeds of members of the subgenera Aculiferum and Acacia (15).

Feeding by the beetles on the three Australian acacias in the subgenus acacia might be tolerated if the beetles could be shown to have much potential for biological control (4,17). However, in my opinion any insect which feeds on mature seeds is unlikely to be effective in Queensland because mature pods tend to be eaten by sheep and cattle as soon as they fall to the ground. Seeds in these pods will pass through cattle and remain viable in cow dung, but will be inaccessible to attack by beetles which will not search for seed in dung. In addition, it appears particularly high levels of seed predation are necessary to have any impact on the population dynamics of long lived perennials with long lived seeds, like prickly acacia (1,3,11,21).

Insects which attack unripe green seeds may be more effective control agents as these insects can access the seeds before they fall to the ground and are fed on by stock. The eurytomid wasp, *Risbecoma capensis* (Walker), is the most promising insect in this category for the biological control of prickly acacia (15). Field survey data and museum collection records indicate *R. capensis* is specific to the subgenera Acacia and Aculeiferum. This means only the seed of *A. farnesiana, A. bidwilli* and *A. sutherlandii* in addition to prickly acacia, are likely to be attacked in Queensland. However, extensive host specificity testing, specifically of the Australian acacias in the subgenus Heterophyllum, would be necessary to confirm this.

R. capensis requires young developing pods for oviposition and larval development. It is thus not possible to rear or test this species until techniques are developed to stimulate pod-set at least in prickly acacia.

Interestingly a seed-feeding Eurytomid, *Eurytoma attiva* Burks, has been successfully used to prevent recolonisation by the weed tree *Cordia curassavica* in Mauritius (12).

Leaf-feeding insects. Seventeen species of insect were found attacking the foliage of prickly acacia in Kenya (15). A more thorough and systematic search in Kenya would probably result in the discovery of many more leaf-feeding insect species.

Interestingly ten of the species are lepidopteran and seven of these belong to the Geometridae. Preliminary host specificity testing of two species of geometrid in Kenya, indicated that one species, *Tephrina new species*, is restricted to the subgenera Acacia and Aculiferum and a second, *Semiothisa inconspicua*, is species specific to prickly acacia (15). I recommend that both species be imported into Australia for further testing at the Alan Fletcher Research Station.

Detailed testing of the Kenyan leaf-feeding chrysomelid beetle, *Weiseana barkeri* Jacoby, was recently completed at the Alan Fletcher Research Station and a report recommending its release in Queensland has been submitted to the Australian Quarantine and Inspection Service. This beetle appears particularly damaging on *A. nilotica* subspecies *indica* (23,14). Continued high levels of attack by leaf-feeding insects have the potential to reduce the fitness of tree species (3). We are hopeful this species will have an impact on *A. nilotica* once released.

Phloem-feeding insects. A large number of phloem feeding insects were found attacking prickly acacia in Kenya. Field surveys and host specificity tests in Kenya indicated that the aphids, two species of Cicadellidae, and eight species of scale insect have an unacceptably broad host plant range being able to feed on Australian acacias and in some instances other leguminous species (15).

Two species of psyllid were found on prickly acacia. Field survey data indicated that one undescribed species was able to feed on several species of Kenyan acacia (subgenera Aculiferum and Acacia) in addition to prickly acacia. A second species, *Acizzia* new species, appeared restricted in its host range to prickly acacia (15). Two attempts were made in Kenya to establish a colony of the *Acizzia* to conduct host specificity tests but both attempts failed perhaps due to fluctuations in relative humidities and temperatures which could not be controlled, due in part to electricity rationing. Muguga, in the Kenyan highlands, is considerably cooler than the arid regions of Kenya were prickly acacia grows.

Following approval from Australian Quarantine services, a shipment of psyllids was sent to the Alan Fletcher Research Station. These insects laid lots of eggs but the first instar nymphs all died without feeding. Given that the psyllid nymphs tend to be more specific than psyllid adults (10), it is possible that *A. nilotica* subspecies *indica*, the subspecies on which they were reared at the Alan Fletcher Research Station is not a suitable host.

Gall midges. The Kenyan acacias are host to an interesting complex of gall midges. I found twenty-eight species galling different species of Kenyan acacia. These species, their galls and acacia hosts are described in Gagné and Marohasy (8). Extensive field survey work established that all except for one species are monophagous (8). Five species attack prickly acacia. I believe three of these species, *Acacidiplosis spinosa* Gagné, *Acacidiplosis imbricata* Gagné and *Aposhizomyia acuta* Gagné, have considerable potential for the biological control of prickly acacia (15).

A. spinosa and *A. imbricata* gall the developing inflorescences, replacing seed pods. To appreciate the biocontrol potential of these midges it is necessary to have some understanding of the reproductive biology of acacias. Acacias and many other leguminous species produce many more flowers than they have the resources to mature (24). Tybirk (25) estimated that in prickly acacia 0.3% of flowers develop into pods. Flower abscission and pod maturation is probably selective, depending on the order of pollination, the number of developing seeds, pollen source, and available resources (24). However, it appears that prickly acacia trees can not abort the galls (as they can abort excess flowers) and that these galls act as energy sinks, consuming resources which would otherwise be available for pod maturation. Successful biocontrol of *Acacia longifolia* has been achieved in South Africa using a galling hymenoptera which operates in a similar way (6). Dennill (6) reports that the wasp sometimes committed *A. longifolia* to the production of 200% more galls per branch than the normal quota of pods. Dennill (6) dubbed this phenomena "forced commitment". Because of "forced commitment" *A. spinosa* and *A. imbricata* have perhaps more potential than other Kenyan insects for the biological control of prickly acacia.

I was unable to rear *A. spinosa* in Kenya. The midges would mate in cages but would not oviposit on two year old potted plants of prickly acacia (13). Given the great potential this insect has for biocontrol it would be worth further attempts at rearing in very large cages and with large flowering plants.

A. imbricata is closely related to *A. spinosa*. It may have less potential for biological control principally because the artichoke-like galls formed by this species are much smaller than the spiky galls of *A. spinosa*. The larger the gall, the greater the energy sink and the greater the potential stress on the host plant (6). This gall midge appears to have a broader distribution than the spiky gall midge, being also present in South Africa and Zimbabwe. I did not attempted to rear or test this species.

A. acuta forms a large lumpy gall, typically at the stem apex, inhibiting stem elongation. It is known that stem elongation in *A. nilotica* occurs immediately before the development of buds and flowers and that buds and flowers are only produced on green extending shoots (19). Through the inhibition of stem elongation this midge can thus effectively stop the production of flowers.

I was unable to rear this insect in Kenya (13). It would be worth further attempts at rearing under more controlled temperatures and relative humidities, in larger cages and with larger plants with larger stem-ends.

CONCLUSION

Only eight of the ninety-one insects found attacking prickly acacia in Kenya appear to have potential for biological control. Of these species, the psyllid, *Acizzia* new species, may be too host specific and the wasp, *R. capensis*, and the geometrid, *Tephrina* new species, may be inadequately host specific. The leaf-feeding beetle, *W. barkeri*, and the leaf-feeding geometrid, *S. inconspicua*, appear suitable for release in North Queensland. The gall midges, *A. spinosa, A. imbricata* and *A. acuta*, all appear species specific (8), however, because of a combination of Australian Quarantine and Inspection Service requirements, our current inability to rear the midges and our inability to get potted acacias to flower and pod, the use of these midges as control agents for prickly acacia remains an elusive objective.

Interestingly only three of the seventy-two species of insect found during the biocontrol project in Pakistan (20) were also found on prickly acacia in Kenya. When plants have extensive geographic ranges it is not uncommon that different insect species are found in different parts of their range (7,16,26). Given prickly acacia's broad distribution across the African continent, central Asia and the Indian subcontinent, it is reasonable to expect many more potential biological control agents await discovery in regions distant to Kenya and Pakistan (15).

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SURVEYS FOR THE NATIVE RANGE OF *CLERODENDRUM CHINENSE* AND ITS NATURAL ENEMIES

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Summary. The perennial shrub *Clerodendrum chinense* has become a problem in countries of the South Pacific. In response to requests to assist in control of the weed preliminary surveys for the weed's native range and its natural enemies were conducted. The native range of *C. chinense* includes southern China and parts of the northern Vietnam border regions. The native range of the apparently closely related *C. chinense* var. *simplex* is wider and includes southern China, a large portion of northern Vietnam and northern Thailand. A wide variety of organisms including insects, fungi and mites were found on these plants. Some caused significant damage, including the leaf feeding beetle *Phyllocharis undulata*, a gall fly, stem tunnelling beetles and leaf attacking fungi. I concluded that a biological control project would identify suitable control agents for release in the South Pacific.

INTRODUCTION

Honolulu rose, *Clerodendrum chinense* (Osbeck) Mabberley (Verbenaceae), is widespread in the tropical and subtropical world as an ornamental shrub. It grows one to three metres tall, has attractive large, serrated edged leaves and white/pink to mostly white, sterile, double flowers in terminal clusters. It is part of a large genus of trees, shrubs and vines native to Africa and southern and eastern Asia.

C. chinense has become a problem in several countries in the South Pacific, namely Western Samoa (first recorded in 1955), American Samoa (no records), Fiji (1940) and Niue (1956). It is rated second most important weed in Western Samoa, high among the top 10 weeds in Fiji, among the 10 most important weeds in Niue and is rapidly becoming a major weed on American Samoa (9).

This weed has invaded fertile, humid lowlands and foothills, areas important for cultivation, estate crops and pastures as well as roadsides and wasteland (6). Weed clumps to several hundreds of metres diameter occur in Western Samoa and the diameter of clumps increase 6 to 8 m per annum in open areas and 2 m in forested areas. Within clumps, on average 11 stems per square metre with height 1 to 3 m provide 25-100% ground cover, dominating other species (2). The weed poses serious problems for relatively poor farming and subsistence communities. Chemical control is too expensive. Regrowth is rapid following chemical control or hand pulling because underground stems remain intact.

Western Samoa and Fiji requested assistance from ACIAR for biological control of this weed. As a result surveys were conducted in South East Asia and China with the following aims:

- to locate the plant and identify its native range;
- to make preliminary collections of organisms attacking the plant; and
- to determine whether a biological control project could be expected to find natural enemies suitable for release in the South Pacific.

PLANT TAXONOMY

Synonyms of *C. chinense* included *Clerodendrum fragrans* (7) until 1968 when it was found that the first valid name was *C. philippinum* Schauer (1847) (1). Until then many workers treated *C. fragrans* and *C. philippinum* as separate species or *philippinum* as a synonym of *fragrans*. Subspecific forms of *philippinum* were recognised: *C. philippinum* having double flowers without functional anthers or stigma; *C. philippinum* var. *subfertile* (5) having many or all flowers fertile and *C. philippinum* var. *simplex* having single fertile flowers. Other variety names were used, *multiplex*, *philippinum* and *pleniflorum*, that appear to be synonyms of *C. philippinum*.

In 1987, Mabberley pointed out that the first valid name was *C. chinense*, established by Osbeck in 1757. The type specimen was collected in southern China in 1751 but had been misplaced in the bromelaid genus *Cryptanthus*.

In this paper, as in the author's survey reports to ACIAR (1992) and Waterhouse (1993), the sterile, double flowered, weedy species will be referred to as *C. chinense* (Osbeck) Mabberley or Honolulu rose, and the fertile, single flowered plant as *C. chinense* var. *simplex*.

SURVEYS IN SOUTH EAST ASIA AND CHINA

Distribution and habitat of *Clerodendrum* in South East Asia and China. Surveys were conducted in northern and south-eastern Thailand, northern Vietnam and southern and eastern China.

Honolulu rose was common in southern and eastern China and in one area in northern Vietnam near the Chinese border, and was later found in Quang Ngai Province, central Vietnam. It was growing as a garden ornamental in Kao Yai National Park in south eastern Thailand, in southern Vietnam and in a village near Hanoi.

Its habitat included roadsides and pathways, banks of waterways, edges of cultivation, in pasture land and especially in unused areas that were partly shaded. Numerous plants were always found together at each location. Phenology of the plant varied with habitat from single stemmed, small leaved plants, less than 50 cm high on exposed dry areas, to shrubby clusters of stems exceeding 2 m in damp, shaded areas.

C. chinense var. *simplex*, was very abundant throughout northern Vietnam and common in northern Thailand and southern and eastern China. It grew in similar habitats to the double flowered plant, and although both forms were sometimes found in close proximity in China they were never mixed.

Both forms (Honolulu rose and var. *simplex*) were surveyed in detail since they appeared to be close taxonomically and have similar habitat requirements where they overlap. Of the two forms, the native range and abundance of var. *simplex* was much greater. If indeed these two forms are genetically close and have similar chemical and morphological characteristics, potential biological control agents may be found on either plant form.

Other species of *Clerodendrum* were also surveyed, particularly *C. paniculatum* (the pagoda plant) which hosted fungi that also attacked Honolulu rose and var. *simplex*.

Organisms associated with *Clerodendrum* species in South East Asia and China. A wide variety of organisms including fungi, mites and insects were found in association with the two forms of *C. chinense*. Those thought to be host specific and those about which little is known are included in Table 1. Numerous other species not included are known to attack other plant species. Several individuals and groups are of particular interest.

Phyllocharis undulata is a leaf eating beetle that attacked var. *simplex* in Vietnam causing considerable destruction in localised areas. This insect has been taken to Thailand and released onto var. *simplex* and onto cultivated plants of Honolulu rose where it has established (B. Napompeth, pers. comm., 1991).

An unidentified gall fly caused stem and leaf galls on var. *simplex* in China and Vietnam in areas where the weedy form did not occur. The damage caused deformation, stunting and reduced numbers of leaves and flowers.

Several fungi, a rust *Endophyllum superficiale* and a *Cercospera* like fungus, were found attacking both flower forms.

A variety of beetles were found damaging both plant forms of the plant. The most interesting appeared to be Cerambycids and Buprestids that damaged stems, Curculionids that damaged stems and leaves and Chrysomelids that fed on the foliage.

Should biological control of this weed be pursued, early studies conducted in Vietnam and China should aim to determine the biology and host range limits of *P. undulata* and the gall fly and the stem and leaf damaging beetles.

DISCUSSION

It is interesting that Honolulu rose has been widespread, mainly as an ornamental, occurring in over 90 countries, but has only recently become a problem and only in the South Pacific (8). In contrast, var. *simplex* is known from 12 countries, mostly in South East Asia, China, countries west to Nepal and Pakistan, Japan and the Philippines and Cuba. It is not considered weedy.

The general use of the name *C. chinense*, or its synonyms, *C. philippinum* or *C. fragrans*, for both Honolulu rose and var. *simplex* lead to considerable confusion when assessing the literature and corresponding with collaborators. The relationship between the two forms is not known; there are minor morphological differences, such as density of leaf hairs, as well as the floral and reproductive differences. Honolulu rose may derive from a mutation of the fertile *C. chinense* var. *simplex*. However var. *simplex* has a much larger southern range in South East Asia than Honolulu rose. Studies are needed on the relationships between the different taxa of *Clerodendrum*. This would help determine the plant species or varieties, and therefore the geographic range, to survey for biological control agents. It would also assist in interpretation of host specificity tests of potential control agents.

The results from the surveys indicate that if a biological control project is undertaken against Honolulu rose the exploration phase should be based in southern China and include work in northern Vietnam. Wider surveys than those already conducted for the plant would improve knowledge of the native range and provide limits for exploration for natural enemies.

Table 1. Organisms found associated with *Clerodendrum chinense* (C2) and *C. chinense* var. *simplex* (C6) in Thailand, Vietnam and China.

ACARINA: unidentified C2

COLEOPTERA: 11 unident. C2 C6.

Apionidae (1 unident. C2; *Lobotrachelus* 2 spp. C2). **Brentidae** (6 unident. C2 C6). **Buprestidae** (1 unident. C2). **Agrilinae** (2 unident. C2). **Cerambycidae** (1 unident. C2). **Lamiinae** (3 unident. C2). **Chrysomelidae** (Bruchinae - 1 unident. C2; Cassidinae - *Aspidomorpha fuscopunctata* C2, *Cassida* sp. C2. Chrysomelinae - *Phyllocharis undulata* C2, Criocerinae - *Lema chujoi* C6, *Lema indica* C2, *Lema saigonensis* C2, *Lema testacea* C6, *Luperomorpha birmanica* C2. Eumolpinae - *Aoria bowringii* C2, *Platycorymus bicavifrons* C2. Galerucinae - *Haplosomoides annimita* C2 C6, *Haplosomoides appendiculata* C2, *Haplosomoides costata* C6, *Hoplosoma* sp.? C2, *Hoplosoma unicolor* C2 C6, *Hyphasis parvula*? C2, *Hyphasis* sp.1 C2 C6, *Hyphasis* sp.2 C6, *Monolepta signata* C2, *Nisotra* sp. nr. *madurensis* C2, *Sebaethe lusca*? C2, *Sebaethe* sp.1 C2, *Sebaethe* sp.2 C6, *Taumacera biplagiata* C2). **Coccinellidae** (6 Unident. C2 C6). **Curculionidae** (13 unident. C2 C6, *Blosyrus* sp. C2, *Hypomeces squamosus* C2, *Mecysolobus* sp. C2, *Myllocerus* sp. C2, *Tanymecini* sp. C2 C6, Cleoninae - 1 unident. C2. Entiminae - 1 unident. C2. Platypodinae - 1 unident. C6. Scolytinae - 1 unident. C2). **Elateridae** (2 unident. C2 C6). **Melyridae** (Prionocerinae, 1 unident. C2). **Mordellidae** (1 unident. C2). **Nitidulidae** (1 unident. C2, *Aethina* sp. C2). **Phalacridae** (2 unident. C2). **Ptilodactylidae** (*Ptilodactyla* sp. C2). **Rhychophoridae** (1 unident. C2). **Rhynchitidae** (1 unident. C2). **Scalytidae** (1 unident. C2). **Scarabaeidae** (9 unident. C2 C6, *Anomala* sp.? C2, *Protaetia* sp.? C2, Rutelinae - 1 unident. C2, Scarabaeinae - 1 unident. C2). **Sciritidae** (*Scirtes* sp. C2). **Scolytidae** (*Xyleborus* sp.? C2).

DIPTERA:

Cecidomyidae (1 unident. C2).

HEMIPTERA: 1 unident. C2 C6.

Aleyrodidae (1 unident. C2). **Aphididae** (? unident. C2 C6). **Cercopidae** (1 unident. C2). **Cicadellidae** (*Tettigoniella ferruginea* C2). **Coccidae** (1 unident. C2). **Coreidae** (1 unident. C2, *Serinetha* sp.? C2). **Flatidae** (1 unident. C2). **Lygaeidae** (1 unident. C2). **Miridae** (1 unident. C2). **Plataspididae** (*Coptosoma* sp. C2). **Pseudococcidae** (2 unident. C2 C6). **Pyrrhocoridae** (*Physopela gutta* C2). **Tingidae** (1 unident. C6).

LEPIDOPTERA: 10 Unident. C2.

Arctiidae (4 unident. C2). **Cossidae** (2 unident. C6). **Lycaenidae** (1 unident. C2). **Phychidae** (1 unident. C2). **Pterophoridae** (1 unident. C2 C6). **Pyralidae** (3 unident. C2, *Archips micaceana* C2). **Tortricidae** (1 unident. C2).

ORTHOPTERA:

Acrididae (1 unident. C2, *Catantops* sp. C2, *Oxya diminuta* C2, Catantopinae - 1 unident. C2). **Pyrgomorphidae** (1 unident. C2). **Tettigoniidae** (*Phaneroptera* sp. C2).

FUNGI:

Endophyllum superficiale C2 C6, *Cercospora* sp. C6.

The number and diversity of organisms found during these preliminary surveys is encouraging for biological control. I concluded that a biological control project is likely to identify host specific natural enemies that could be released in the South Pacific to control *C. chinense.*

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THE INVASION AND CONTROL OF *TAMARIX APHYLLA* ON THE FINKE RIVER, CENTRAL AUSTRALIA

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Summary. The native ecology of the Finke River is being damaged by the wide scale invasion of Athel pine, *Tamarix aphylla*. A control programme has been implemented in the Finke and other rivers of central Australia and basal bark and stem injection chemical control trials are being conducted.

INTRODUCTION

Athel pine (*Tamarix aphylla*) is native to northern Africa, the Arabian Peninsula, Iran and India. It was introduced to Australia from California around 1930 as a shade and ornamental tree and was first planted in central Australia in the 1950s. Over the past 18 years Athel pine has become established along several hundred kilometres of the Finke River in the Northern Territory. Major flows in the Finke River in 1974 dispersed seed along its entire length, and the wet conditions that followed were ideal for seed establishment. Further floods in 1983 and 1984 enabled more Athel pine to establish, from seed and vegetable matter, probably from those trees established in the 1974 floods. A small infestation also exists in the Ross River east of Alice Springs. All infestations originated from trees planted around homesteads and communities for shade.

The presence of infestations of the tree over large areas is likely to have deleterious effects for the pastoral industry and conservation of the natural environment. Athel pines tolerate saline water and exude large quantities of salt through their leaves. They alter several ecosystem properties with subsequent effects on native flora and fauna. Few native herbs persist under the dense infestations and the number of birds and reptiles are reduced where native species have been displaced. Presence of the trees may alter the course of rivers and increase sedimentation rates (1).

The genus has also been studied in the United States of America (USA), where it is a major pest of deserts. *Tamarix* species cover over 500,000 ha of river systems and flood plains in the USA and has been associated with huge reductions in native animals and grasses. In the USA the genus is reported to have higher water usages than native species, desiccating springs, pools and perennial streams.

Athel pine has the potential to invade all central Australian river systems. It was therefore declared as a Class B noxious weed in 1988. The strategy for its control is:

(i) to eradicate plants from homesteads by chemical and physical means in order to prevent invasion of non infested rivers;
(ii) to eradicate small infestations already in river systems such as the Ross River and Palmer River; and
(iii) to begin control in the Finke River working from the headwaters downstream and to prevent the spread of the tree further downstream from the lowest point of infestation.

In 1989 a screening trial was carried out to determine which herbicides and application methods would be effective in killing Athel pine. Stem injection with concentrated products of 2,4-D ester, triclopyr, fluroxypyr, 2,4-D amine plus picloram and triclopyr plus picloram gave 100% kills. Basal bark treatments of fluroxypyr and triclopyr mixed with diesel at 1:50 gave in excess of 80% kills (2).

The aims of the experiments described here are to further refine rates of application of herbicides by basal bark treatment and stem injection, to determine the growth stages at which basal bark treatment is effective, and to determine an appropriate cut spacing for stem injection.

METHODS

Athel pine often occurs in clumps. This is because young trees are pushed over by floodwaters and vertical branches appear to be separate stems or trees. This therefore presents difficulties in designing herbicide trials as the stems in clumps may well be connected. Some of the kill ratings of trees in the screening trial may have been ratings of vertical branches of the one tree. Because of this uncertainty the following experiment was designed to assess the kill of stems, rather than the kill of individual trees.

The experiments were conducted on New Crown Station in the Finke River system.

<u>Experiment 1 - Basal Bark Treatments.</u> Garlon 600 (600 g/L triclopyr) and Starane (300 g/L fluroxypyr), mixed in diesel, were applied to juvenile, intermediate and mature stems in a randomised block design with four replications. Each plot consisted of groups of 5 to 10 stems and each stem was sprayed to a height of 45 cm above ground level. The volume of herbicide applied per stem varied depending on its size.

The herbicide concentrations were 1:60, 1:100 and 1:120. There were two types of control: control (i) - diesel alone, and control (ii) - no treatment.

The diameter of stems were recorded at application. Visual observations are being made of herbicide symptoms, the defoliation response and regrowth. The number of dead stems is to be recorded 6, 12 and 18 months after herbicide application. Percentage kill data will be arcsin transformed and analysed as a herbicide rate x growth stage factorial analysis of variance to determine significant treatment effects.

<u>Experiment 2 - Stem Injection.</u> Estone 80 (800 g/L 2,4-D ethyl ester), Garlon (480 g/L triclopyr), Starane (300 g/L fluroxypyr) and Tordon TCH (100 g/L triclopyr plus 50 g/L picloram) were injected into mature stems at waist height in a randomised block design with four replications. Each plot consisted of groups of 5 to 10 stems. Two cut spacings were tested: 13 cm and 25 cm centres, with 2 mL of herbicide applied per cut.

The herbicide concentrations were 100%, 50% and 25% product and a water injection control.

Visual observations will be made of herbicide symptoms, the defoliation response and regrowth. The number of dead stems will be recorded at 6, 12 and 18 months after herbicide application. Percentage kill data will be arcsin transformed and analysed as a herbicide x rate x cut spacing factorial analysis of variance to determine significant treatment effects.

RESULTS

At the time of writing only the 6 month recordings had been made. Results will not be analysed until the 18 month recordings have been carried out (February 1994).

Past control has been carried out using Garlon 600 at 1:60 with diesel. This gives 100% stem kills. However, field observations from the trial indicate that Garlon 600 mixed with diesel at 1:100 will give greater than 95% kill for trees up to 150 mm diameter that have not developed a hard mature bark.

Starane does not appear to be as effective on immature stems at 1:60. No conclusions can yet be drawn from the stem injection trial.

DISCUSSION

The basal bark treatment of Athel pine in the Finke River is continuing. The Tjuwanpa Outstation Resource Centre and the Aputula Community have been funded by the Bureau of Rural Science, Australian Nature Conservation Agencies, Save the Bush and the National Landcare Programme to work in conjunction with the Northern Territory Department of Primary Industry and Fisheries to carry out this control.

Until trial results are more conclusive basal bark control will continue using Garlon 600 at 1:100 and 1:60 depending on tree size. Stem injection will continue using Tordon TCH at 2 mL per cut, with cuts at 13 cm spacings.

Athel Pine has been eradicated from the headwaters of the Finke River to the Stuart Highway, a distance of 200 km. It is anticipated that it will be totally eradicated from all central Australian rivers by 1998.

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ALTERNATIVE HERBICIDES FOR GRASS CONTROL IN LEGUME PASTURES

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Summary. Post-emergence herbicide treatments were tested for control of silver grass *(Vulpia myuros)*, annual ryegrass *(Lolium rigidum)* and volunteer barley *(Hordeum vulgare)* in subterranean clover *(Trifolium subterraneum)*, and for control of barley grass *(H. leporinum)* and red fescue *(Festuca rubra)* in medic *(Medicago* spp.) in South Australia in 1992. Carbetamide at 1750 g/ha gave the best control but is expensive. Clethodim + simazine at 60 + 400 g/ha gave moderate grass control with satisfactory legume tolerance, but the possibility of herbicide resistance is a concern. Simazine + paraquat at 400 + 40 or 400 + 60 g/ha also gave moderate grass control with satisfactory tolerance by both clover and medic. Paraquat at 150 g/ha temporarily suppressed clover growth and caused unacceptable damage to medic.

INTRODUCTION

The cost of the cereal root disease, take-all *(Gaumannomyces graminis* var. *tritici)*, has been estimated at $100-200 million p.a. across southern Australia (1,6). The major control strategy is through rotation with non-cereal crops although the practice of removing grasses (the disease hosts) in the pasture phase is of increasing importance. Both these techniques rely heavily on the use of selective grass herbicides and are therefore under threat from the development of herbicide-resistant grasses (11). Furthermore, these selective herbicides do not control *Vulpia* species (silver grasses) (8).

The use of herbicides to control grasses in pastures is expected to increase because it is a relatively simple and cost-effective technique, there is increasing evidence of the value of the pasture phase of rotations in sustainable farming systems, and it is one of the few effective options for cereal root disease control in low rainfall areas where grain legumes or oilseeds are not suitable.

Research in Western Australia suggests that the incidence of take-all increases by about 5% for each 100 kg/ha of grass dry matter in spring in the previous year's pasture (10). In South Australia, take-all was controlled when grass comprised 5% or less of the previous year's pasture (6).

The principal aims of 2 field experiments conducted in South Australia in 1992 were to investigate alternative herbicide strategies for the control of grasses in pastures that would:

(1) reduce the grass component to a level that would provide control of take-all,
(2) provide options to the currently available selective grass herbicides in order to reduce selection pressure for the development of herbicide-resistant grasses,
(3) provide adequate control of silver grass, and
(4) exhibit acceptable safety to pasture legumes.

METHODS

Post-emergence herbicide treatments were applied on 25 June in a medic pasture at Palmer (sandy loam, pH 8.2) and on 16 July in a subterranean clover pasture at Marrabel (clay loam, pH 6.1) in South Australia in 1992. Treatments were applied with a hand-held, 2 m-wide spray boom delivering 85 L/ha of spray mixture.

Grasses present at Marrabel were silver grass, annual ryegrass and volunteer barley. Barley grass was present at the Palmer site which was expected to also contain silver grass, but this was later provisionally identified as red fescue. Because of the early break to the season in South Australia in 1992, the grasses were well advanced (tillered) at the time of spraying.

Experimental design was a randomised complete block with 4 replicates and 12x3 m plots. Data were handled by analysis-of-variance techniques.

Effects of the herbicide treatments were assessed at both sites by visual inspections and by measuring the percentage ground cover of each species in grazed sections of the plots. Herbage was cut and oven-dried to determine pasture production (dry weight) and composition.

At Marrabel, cuts were taken from ungrazed pasture in 3 replicates on 21 September to determine total pasture dry weight, and from lightly grazed pasture in 2 replicates on 2 November. Equipment failure prevented any further sampling at the later date. The proportion of grass and clover in the samples from the later harvest was estimated visually, with reference to the ground cover measurements of 27 October.

At Palmer, herbage was cut from ungrazed pasture in all plots on 13 October and sorted into species to determine the proportion that each component contributed to total dry weight.

Results from some herbicide treatments are not reported in this paper but were included in the statistical analyses. Imazethapyr at 40 g/ha, mixed with paraquat or simazine, had little effect on grass control. Spraying oil added to several of the herbicide treatments also had little effect.

RESULTS AND DISCUSSION

Marrabel. All herbicide treatments significantly reduced total pasture dry weight on 21 September. Paraquat at 150 g/ha, followed by both simazine+paraquat mixtures, gave the largest decrease (44-66%). It is probable that many of the herbicide treatments suppressed clover production, since this was the main component of the pasture, but quantitative data were not obtained.

The light grazing that occurred prior to 2 November may have partially masked differences between treatments, and the harvesting of only 2 replicates decreased the sensitivity of the statistical analysis. Given these limitations, no treatment significantly reduced clover or total dry weight on 2 November. Several treatments significantly reduced grass dry weight, with 1750 g/ha carbetamide and clethodim+simazine giving complete grass control (Table 1).

These results are supported by the ground cover measurements on 27 October, where carbetamide and clethodim+simazine were the only treatments to significantly decrease grass ground cover and significantly increase clover cover.

Table 1. Pasture dry weight (kg/ha) at Marrabel, 2 November 1992

Treatment and rate (g/ha)	Clover	Grasses	Total
Untreated	2556	639	3195
Paraquat (150)	3074	1019	4093
Carbetamide+paraquat			
(350+40)	3269	577	3846
(700+40)	2895	102	2997
Simazine+paraquat			
(400+40)	3086	250	3335
(400+60)	2833	58	2891
Clethodim+paraquat (60+40)	3098	356	3453
Carbetamide (1750)	3479	0	3479
Carbetamide+simazine			
(350+400)	3119	15	3134
(700+400)	3207	36	3242
Clethodim+simazine (60+400)	2985	0	2985
l.s.d. (5%)	n.s.	478	n.s.

Some herbicide treatments containing paraquat initially reduced clover vigour which allowed grasses, especially silver grass, to increase in proportion. This effect was most obvious with 150 g/ha paraquat. The clover recovered as the season progressed but the proportion of grass remained higher than in untreated pasture (Table 1) and, according to percentage ground cover measurements, was significantly higher for silver grass.

Palmer. Most herbicide treatments significantly reduced barley grass dry weight, but fewer significantly reduced total dry weight (Table 2). Paraquat at 150 g/ha caused severe medic damage, but 40-60 g/ha in mixtures with other herbicides was acceptable. The ground cover measurements in grazed areas showed that there was a higher percentage of bare ground where barley grass was controlled.

The herbicide treatments that significantly decreased barley grass dry weight also decreased the proportion of barley grass in the pasture. Carbetamide, both carbetamide+simazine treatments, and simazine+paraquat at 400+40 g/ha significantly increased the proportion of medic in the pasture.

Conclusions. Carbetamide at 1750 g/ha gave the best grass control but is an expensive treatment (approximately $65/ha). Lower rates (350 and 700 g/ha) were tested in mixtures with paraquat or simazine, in order to reduce the cost of treatment, but grass control suffered as a result. It appears that at least 700 g/ha carbetamide is needed for acceptable grass control and that carbetamide+simazine is more promising than carbetamide+paraquat.

Other research has shown that a mixture of a selective grass herbicide with simazine can give good control of a range of grass weeds including silver grass (6,9). Such mixtures do not overcome the threat of herbicide resistance. If they are used in the pasture phase, selective grass herbicides should not be applied in the crop phase (5).

Clethodim was the selective grass herbicide used in these experiments because it has some activity on silver grass at high rates (2,3,4,7,12). Unfortunately, it has poor activity on barley grass (7) which was the dominant weed at Palmer. An alternative grass herbicide, such as fluazifop, would have been more appropriate in this situation.

Mixtures of simazine with paraquat controlled silver grass and other annual grass weeds in southern New South Wales (9). Similar treatments in South Australia have sometimes given unsatisfactory control of grasses other than silver grass (13). At rates that exhibit acceptable safety to pasture legumes, mixtures of simazine with paraquat may not control all grasses well enough to effectively reduce take-all. Nevertheless, these treatments merit further investigation as they are relatively cheap and offer an alternative to the selective grass herbicides. Based on the results from this experiment and on other research experience, application to young plants and/or an increase in the paraquat rate above 60 g/ha may be necessary to achieve a satisfactory level of grass control. This is likely to increase the risk of pasture legume damage (especially in medics) and reduce feed availability during winter, but may be the price that has to be paid if take-all is to be controlled.

Table 2. Pasture dry weight (kg/ha) at Palmer, 13 October 1992

Treatment and rate (g/ha)	Medic	Barley grass	Fescue	Broadleaf	Total
Untreated	1156	1104	0	80	2340
Paraquat (150)	471	104	84	310	869
Carbetamide+paraquat					
(350+40)	856	956	0	46	1858
(700+40)	1158	243	147	91	1639
Simazine+paraquat					
(400+40)	1344	74	26	226	1670
(400+60)	996	290	58	179	1522
Clethodim+paraquat (60+40)	1456	530	0	550	2536
Carbetamide (1750)	1370	0	167	164	1701
Carbetamide+simazine					
(350+400)	1466	369	43	38	1916
(700+400)	1065	96	5	4	1170
Clethodim+simazine (60+400)	1058	980	0	22	2060
l.s.d. (5%)	486	477	n.s.	n.s.	655

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ACTIVATED CARBON IMPROVES THE TOLERANCE OF LETTUCE TO MIXTURES OF NAPROPAMIDE WITH DIURON OR PROMETRYNE

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Summary. Propyzamide selectively controls weeds in lettuce, however, it is not effective against weeds of the same botanical family and chemicals that are effective also kill lettuce. To overcome this problem several means were tested of applying activated carbon to protect lettuce against various herbicides and herbicide mixtures in the glasshouse and field. Field treatments included mixtures of propyzamide (3 kg/ha) with napropamide (1, 2 and 3 kg/ha), linuron (0.5, 0.75 and 1 kg/ha), diuron (0.5, 0.75 and 1 kg/ha), propachlor (0.5, 1 and 2 kg/ha) or prometryne (0.25, 0.5 and 0.75 kg/ha). All mixtures provided excellent weed control and activated carbon applied above the lettuce seed at sowing protected the seedlings against mixtures containing napropamide, diuron and prometryne but to a lesser degree against those containing linuron and propachlor. A prototype machine has been developed to sow seed and apply activated carbon over the seed prior to herbicide application.

INTRODUCTION

In common with other *Asteraceae*, lettuce is relatively tolerant of the herbicide propyzamide which is used to selectively control weeds in lettuce crops throughout Australia. The crops are predominantly grown near the coast, where potato weed (*Galinsoga parviflora* Cav., also a member of the *Asteraceae* family) thrives on cultivated land. In this environment, weed seed production (greater that 70,000 seeds per plant) and germination (greater than 20,000 seedlings/plant) continue all year round. Potato weed is resistant to propyzamide, and is the most economically important weed in the production of lettuce in Australia.

Activated carbon adsorbs herbicides (8), and with other adsorbents has been used to protect crops such as lettuce (1) from injury by herbicides and thus enhance selectivity. Toth *et al.* (6) used activated carbon to protect tomato against metribuzin and Taylor and Warholic (5) protected fluid drilled lettuce from various herbicides using activated carbon applied in gels with the seed. Germination of lettuce seed has been shown to be uninhibited by activated carbon (3).

The following experiments were conducted to investigate whether the tolerance of lettuce to pre-emergent herbicides could be improved by placing small quantities of activated carbon near the seed prior to application of the herbicides.

METHODS

Glasshouse trials. The first experiment assessed the effects of 33 herbicide treatments (Table 1) on the growth of both potato weed and lettuce. The most promising 23 treatments (Table 2) were repeated in a second experiment. In both experiments white polystyrene cups were used as pots, each containing ~250 g of air-dry sandy loam. A mixed fertiliser solution was injected into each pot (6) then lettuce was sown into two thirds of the pots (10 seeds/pot) and potato weed into the remaining one third. Activated carbon suspension in water (2 mL containing 0.1 g of carbon) was applied on the soil surface immediately above the seed row in half of the pots containing lettuce. Herbicide treatments were applied and watered-in using a conventional spray nozzle mounted in a specially designed spraying cabinet. Each treatment was replicated four times. Watering was maintained independently for each pot using jute wicks with one end implanted in the soil and the other immersed in water in a reservoir (7). Seedlings were counted at weekly intervals and plants were harvested, dried and weighed four weeks after emergence. The best treatments from the second glasshouse experiment were trialled in the field.

Field trial. In the field trial a randomised split plot design was used with 4 rows of lettuce per plot. There were eighteen main treatments and each treatment was split into 4 sub-treatments (1 row of lettuce). The trial was replicated 4 times. The main treatments included a nil control and a hand weeded control, all other treatments received 3 kg/ha propyzamide alone or in mixture with linuron (0.5, 0.75, 1.0 kg/ha), prometryne (0.25, 0.5, 0.75 kg/ha), diuron (0.5, 0.75, 1.0 kg/ha), propachlor (0.5, 1.0, 2.0 kg/ha) or napropamide (1.0, 2.0, 3.0 kg/ha). The sub-treatments used were seed with no protection, seed in xanthan gum, activated carbon placed on the soil surface above the seed, and seed in xanthan gum with activated carbon. The herbicide treatments were applied using a small compressed air plot spraying apparatus. Lettuce plants were counted 7 days after emergence. They were harvested and weighed green 60 days after planting.

RESULTS AND DISCUSSION

Glasshouse trials. Data from the first experiment clearly illustrate the difficulty of selectively removing potato weed from lettuce since all the effective herbicides were also highly toxic to lettuce (Table 1). It would be a rather simpler task to remove lettuce from a crop of potato weed using butylate, profam or chlorthal! Selection of herbicides for subsequent experiments was therefore strongly influenced by the degree of protection afforded to the lettuce by activated carbon.

Activated carbon enhanced the tolerance of lettuce to all the herbicides, particularly linuron, prometryne and napropamide, as evidenced by both increased survival and weight of seedlings (Tables 1 and 2). However, this beneficial effect is not attributable solely to a reduction in phytotoxicity through adsorption. There are at least two confounding influences. First, activated carbon stimulated germination probably through adsorption of inhibitors (3). With the short duration of the experiments, this caused growth enhancements in the absence of herbicides (Table 2) and perhaps in their presence. Secondly, with linuron in the first experiment and prometryne in the second, increasing the herbicide dose increased dry weight in the presence of activated carbon. This is attributed to incomplete herbicide adsorption, resulting in growth stimulation from the residual low herbicide dose (2 and 4). We find such effects notoriously difficult to reproduce between experiments, but have observed them on several other occasions.

Field trials. There was a wide range of weed species in the experimental area. When no herbicide was applied grasses dominated and weed competition overwhelmed the crop (Table 3). When only propyzamide was applied the grasses and most of the broadleaves were controlled. Potato weed became dominant and the crop yield was reduced by more than 75% compared with the hand-weeded control (Tables 3 and 4).

All the herbicide mixtures provided excellent weed control. Therefore the effects of the treatments on yield are not due to weed competition (Tables 3 and 4). As in the glasshouse experiments the herbicide treatments that controlled the weeds were also toxic to lettuce (Table 3).

Table 1. Effect of treatments on establishment and growth of lettuce and potato weed in the first glasshouse experiment. Plants were harvested four weeks after emergence.

Herbicide treatments		Seedling establishment and growth (dry weight)					
		Lettuce				Potato weed	
		-AC[2]		+AC[2]			
Combination	Rate (kg of ai/ha)	No. of plants	Dry wt. (g)	No. of plants	Dry wt. (g)	No. of plants	Dry wt. (g)
Propyzamide	2.25	34	0.248	33	1.355	120	1.981
	4.50	26	0.357	23	1.147	70	1.693
Propyzamide plus linuron	2.25 + 0.125	28	0.202	27	0.794	106	2.973
	2.25 + 0.250	32	0.388	22	0.611	32	0.634
	2.25 + 0.375	28	0.260	30	1.791	24	0.243
	2.25 + 0.500	31	0.405	33	1.778	22	0.304
Propyzamide plus prometryne	2.25 + 0.125	12	0.099	34	1.866	7	0.009
	2.25 + 0.250	6	0.006	36	1.442	4	0.010
	2.25 + 0.375	9	0.016	34	1.247	3	0.005
	2.25 + 0.500	9	0.042	34	1.313	-	-
Propyzamide plus propachlor	2.25 + 0.65	29	0.324	29	1.334	15	0.027
	2.25 + 1.30	27	0.112	29	0.618	9	0.005
	2.25 + 1.95	23	0.066	28	1.186	6	0.008
Propyzamide plus diuron	2.25 + 0.25	31	0.277	27	1.211	-	-
	2.25 + 0.50	13	0.020	29	1.052	7	0.010
Propyzamide plus napropamide	2.25 + 0.50	29	0.253	37	1.479	96	0.951
	2.25 + 1.00	34	0.312	37	1.713	70	0.138
	2.25 + 1.50	32	0.242	32	1.362	68	0.108
Propyzamide plus diphenamide	2.25 + 0.80	29	0.469	31	0.626	54	0.812
	2.25 + 1.60	23	0.299	21	0.490	42	0.457
	2.25 + 2.40	29	0.282	35	1.016	39	0.468
Bensulide	5.00	28	0.203	33	0.500	86	3.011
	10.00	27	0.172	35	0.557	37	1.228
Butylate	1.00	33	0.073	36	0.541	81	3.040
	2.00	27	0.081	36	0.353	74	2.950
	3.00	25	0.064	36	0.561	99	3.579
	4.00	26	0.073	32	0.612	78	2.651
Chlorthal-linuron (Shamrox®)	3.125	27	0.110	34	0.758	4	0.092
	6.250	26	0.138	35	0.744	-	-
Propham	3.00	30	0.215	33	1.068	99	2.815
	6.00	29	0.087	29	0.642	79	2.554
Chlorthal	7.50	36	0.173	34	0.841	45	2.243
Oryzalin	0.50	27	0.071	35	0.890	-	-

[1] Data are totals for the four replicates.

[2] +AC = activated carbon added and -AC = no activated carbon added.

Table 2. Effect of treatments on establishment and growth of lettuce and potato weed in the second glasshouse experiment. Plants were harvested four weeks after emergence.

Herbicide treatments		Seedling establishment and growth (dry weight)					
		Lettuce				Potato weed	
Combination	Rate (kg of ai/ha)	-AC[2]		+AC[2]		No. of plants	Dry wt. (g)
		No. of plants	Dry wt. (g)	No. of plants	Dry wt. (g)		
Propyzamide	0	36	0.287	32	0.425	62	2.795
	2.25	33	0.307	33	0.311	33	0.997
Propyzamide plus linuron	2.25 + 0.250	33	0.286	38	0.687	19	0.240
	2.25 + 0.375	11	0.098	36	0.432	4	0.027
	2.25 + 0.500	11	0.051	37	0.443	1	0.002
Propyzamide plus prometryne	2.25 + 0.125	34	0.308	32	0.223	22	0.288
	2.25 + 0.250	-	-	32	0.399	10	0.017
	2.25 + 0.375	-	-	33	0.440	6	0.026
	2.25 + 0.500	1	0.002	34	0.624	-	-
Propyzamide plus propachlor	2.25 + 0.65	10	0.054	24	0.222	24	0.063
	2.25 + 1.30	-	-	31	0.226	12	0.039
	2.25 + 1.95	-	-	28	0.226	7	0.009
Propyzamide plus diuron	2.25 + 0.20	27	0.148	31	0.243	20	0.178
	2.25 + 0.40	33	0.188	29	0.205	17	0.015
	2.25 + 0.60	23	0.114	34	0.214	1	0.002
	2.25 + 0.80	3	0.008	33	0.219	1	0.003
Propyzamide plus napropamide	2.25 + 1.00	30	0.153	34	0.223	32	0.412
	2.25 + 1.50	33	0.125	36	0.378	44	0.076
Propyzamide plus diphenamide	2.25 + 1.60	35	0.166	31	0.468	44	0.280
	2.25 + 2.40	34	0.163	35	0.254	33	0.068
Propyzamide plus oryzalin	2.25 + 0.25	33	0.151	36	1.053	12	0.018
	2.25 + 0.50	32	0.116	32	0.726	2	0.003

[1] Data are totals for the four replicates.
[2] +AC = activated carbon added and -AC = no activated carbon added.

Sowing treatments that did not include activated carbon did not reduce the phytotoxicity of the herbicides to lettuce (Table 3). Under these conditions, mixtures containing linuron or diuron were very toxic. Application of activated carbon on the soil surface above the seed gave superior protection compared with its application in xanthan gum (Table 3).

Placement of activated carbon on the soil surface increased lettuce yield in the absence of herbicides as it had done in the glasshouse (Table 3). When herbicides were applied over the activated carbon the optimum rates were linuron (0.5 kg/ha), prometryne (0.25-0.50 kg/ha), diuron (0.75 kg/ha), propachlor (1.0 kg/ha) and napropamide (3.0 kg/ha). However, by comparison with the hand-weeded control, yields were depressed even at the lowest rates of linuron, prometryne and propachlor (Tables 3 and 4). These results have been confirmed in other field experiments at Richmond and Gosford, NSW. In choosing between the optimal rates of diuron and napropamide, horticulturists should consider both the cost of the herbicides and their residual effects on following crops.

Table 3. Weight (g) of lettuce plants 60 days after emergence in the field trial[3].

Herbicide treatments		Fresh weight of lettuce (kg)			
		Sowing treatments			
Combination	Rate (kg/ha)	Seed only	Seed+X[1]	Seed+AC[2]	Seed+X+AC[2]
Nil control	0	0.0	0.0	0.0	0.0
Hand weeded	0	30.4	22.2	33.2	28.6
Propyzamide	3	5.4	7.1	7.9	6.7
Propyzamide plus linuron	3 + 0.50	0.0	0.0	25.4	6.4
	3 + 0.75	0.0	0.0	9.7	2.3
	3 + 1.0	0.0	0.0	11.3	0.3
Propyzamide plus prometryne	3 + 0.25	12.3	10.6	27.5	19.4
	3 + 0.50	4.4	3.0	28.0	17.2
	3 + 0.75	1.4	2.4	20.7	14.8
Propyzamide plus diuron	3 + 0.50	0.5	0.1	29.9	13.0
	3 + 0.75	0.0	0.0	34.7	3.0
	3 + 1.00	0.2	0.0	23.0	3.7
Propyzamide plus propachlor	3 + 0.5	16.1	12.7	21.9	19.5
	3 + 1.0	11.3	5.8	26.1	18.4
	3 + 2.0	1.7	6.3	24.4	13.1
Propyzamide plus napropamide	3 + 1.0	4.9	8.0	30.9	11.6
	3 + 2.0	0.7	2.1	31.3	8.6
	3 + 3.0	0.2	0.3	35.2	2.3

[1] X = xanthan gum.
[2] AC = activated carbon added.
[3] Data are total for the four replicates.

Table 4. Lettuce yield in the field experiment relative to the hand weeded control when activated carbon applied on the soil surface is used to protect the seed.

Treatment	Lettuce yield as a per cent of hand weeded control calculated for different herbicide application rates[1]		Comments
	Optimum rate[2]	Average for three rates[2]	
Nil treatment	0.0	0.0	Weeds completely overgrew the plots
Propyzamide	23.8	23.8	Potato weed reduced yield on these plots
Propyzamide plus linuron	76.5	46.5	No weeds
Propyzamide plus prometryne	84.5	76.5	No weeds
Propyzamide plus diuron	104.5	88.0	No weeds
Propyzamide plus napropamide	105.9	97.7	No weeds

[1] Data calculated from Table 3.
[2] Rates given in Table 3.

As a result of these experiments a prototype machine has been developed to sow seed and apply a small patch of activated carbon on the surface of the soil above the seed prior to herbicide application.

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RESEARCH NEEDS FOR MANAGING POTENTIAL WEED PROBLEMS IN THE MALAYSIAN AGRICULTURE INDUSTRY

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Summary. Weed science research in Malaysia is relatively young and is often dominated by site-specific empirical studies which almost always compare the effects of different control measures or herbicide application techniques. As a result several issues confronting weed science have emerged over the last decade, including increased weed resistance, emergence of new weed problems, growing public concern on indiscriminate pesticide use and its effect on environment and human health, and increased regulatory restraints on herbicide development. The greatest challenge to weed science research, therefore, is to develop a control technology that will integrate the ecological, physiological, demographical and morphological responses as crops and weed interact with their environment and with each other. This paper outlines thrust areas for research, priorities and development approaches required as well as specific studies for weed science.

INTRODUCTION

The problems confronting the agriculture industry in Malaysia with respect to weeds and the current management practices available for oil palm, rubber, cocoa, orchards, field crops and rice have been reviewed elsewhere (1).

Plantation crops have dominated the agricultural scene in Malaysia over the last few decades, and by 1990 the area under rubber, oil palm, cocoa and rice had reached 1.86, 1.78, 0.36 and 0.64 million hectares respectively. In terms of export earnings, the three main crops, rubber, oil palm and cocoa constitute about 21.1% of the country's total earning amounting to 11.67 billion ringgits. For the country to maintain its competitive edge in the international market it has to be an efficient producer, which can only be achieved by obtaining high yields of crops and through reduction in the cost of production. One of the important production inputs is the management of weeds and the significance of this is reflected in the high expenditure of herbicides compared with other pesticides. Oil palm, rubber and cocoa are the three main crops that used large quantities of herbicides, approximately 80% of the total herbicides in 1990. Despite the significant progress in various control measures, it is estimated that weeds still cause losses in excess of 10% of the country's agricultural production per year.

A major void in the design and conduct of experiments to reveal the environmental impacts of new technology is the lack of understanding of the diversity of ecosystems under which crops are grown and of specific crop ecosystems in relation to their weeds. More basic information is needed on the prevalence and importance of native beneficial organisms and how they relate to each other and their pest hosts. Knowledge about the interactions within pest complexes and between host and pest populations is needed. Satisfying these basic ecological information needs would provide a much stronger foundation upon which to develop research programmes that would yield acceptable data on environmental impacts.

THRUST AREAS FOR RESEARCH IN WEED SCIENCE

For the coming decade and beyond, researchers have come to recognize that they must develop a more thorough understanding of the basic biology of weeds. Studies on biochemistry, ecology, population dynamics and allelopathy are needed. Competition threshold calculations are required for specific weeds and crops. A better comprehension of the life cycles and growth stages of weeds, particularly of perennial and biennial species must be understood. In addition, more attention is required on plant and seed dormancy and their impacts on the efficacy of weed control tactics. A more thorough understanding of plant metabolism is needed to study translocation of herbicides and growth regulators and to evaluate the resistant and reactive sites of herbicides. The residual properties of herbicides in soil and water require attention and their degradative and metabolitic products need to be identified. An important technological area requiring additional research emphasis is the adverse effects on non-target environmental components of volatility, drift and misuse of herbicides.

These are some of the thrust areas where research is needed to strengthen, diversify or develop new weed control technology, and on which research institutions, universities and the R & D department in the plantation sector should focus.

PRIORITIES AND DEVELOPMENT APPROACH REQUIRED

At least five major activities have been identified at the national level where emphasis is to be given by researchers engaged in weed science and related areas. These are to:

(i) develop relevant control technology based on the ecophysiology and demography of weeds, including biological control of noxious weeds;
(ii) continue biological studies of selected weed species including seed dormancy, germination and life cycle (growth and development) in order to elucidate their persistence in soil and the controlling factors for their germination and competitiveness;
(iii) elucidate the degree of weed colonization and of weed shift in selected agricultural systems as influenced by cultivation practices, continued use over years of similar control measures and other factors;
(iv) study the mode of action of novel herbicides, safening and other adjuvants; and
(v) improve and refine herbicide application technology.

Innovative approaches in weed control, e.g. using herbicide-resistant crops via biotechnology is also on the agenda for evaluation but this would be the preserve of chemical and biotechnology firms rather than research institutions, universities or the plantation sector.

PROGRAMME AREAS IN WEED SCIENCE

Specific research programmes for weed science have been drawn up by bringing into focus the thrust areas and priorities outlined above. Both basic and applied studies will be tailored to the needs and requirements of realizing the full potential for weed management in the major crops in the agricultural industry. Some of the research programmes identified are listed below.

Weeds in field crops

1. Biological control of major weeds in waterways. Particular emphasis is given to salvinia and water hyacinth. That for salvinia is completed where the impact of *Cyrtobagous salviniae* on its control have been quite significant in three of the areas evaluated. That for waterhyacinth looks promising with the introduced biological agent *Neochetina bruchi*.

2. The control of the noxious weed *Mikania micrantha* in oil palm, rubber and cocoa/coconut plantations is being studied through biological means with the use of the natural enemy *Liothrips mikaniae*. Two years of study have given mixed results on the efficacy of the introduced biological agent but more work in this area is being pursued.

3. The study on the biology, spread and control measures of four important weed species that are beginning to encroach into rubber, oil palm and cocoa and cane growing areas. These are *Asystasia* spp., *Mimosa pigra*, *Pennisetum polystachion* and *Rottboellia cochinchinensis*. For *M. pigra*, work on biological control has started in collaboration with CSIRO.

4. Phytotoxicity studies of some promising broad spectrum herbicides for use in cocoa. The studies will involve bioassays for residual activities of herbicides in soils and phytotoxicity to cocoa seedlings.

5. For weed management in fruit orchards, refinement of control measures both cultural and chemical are given emphasis which will include phytotoxicity tests for several new herbicides.

6. Development of cost effective systems for weed management in some of the important field crops including maize, cassava and sugarcane. Screening of more suitable chemicals will continue.

7. Maintenance of vegetation cover under different inputs and management systems for plantation crops and fruit trees.

8. Monitoring of herbicide residues in rice ecosystems, vegetables, fruits and in soils and groundwater.

9. Ecology of plant communities in tin-tailing areas. Little is known of the population dynamics of the natural vegetation and those of pioneer plant species that colonize large tracts of land. Baseline information is sought as to how best the natural vegetation can be manipulated for the success of reclamation and for growing of crops subsequently.

10. Programmes on herbicide application technology, safety and handling of chemicals are also being defined especially for orchards, field crops and vegetables.

These research activities have been designed and planned in such a way that the development of weed control technology must emphasize studies on biology and ecology, biological control, and low-cost herbicide development. Consideration will be given to safety aspects in herbicide application technology and integrated management for weed control. The primary concern must be that all such activities be geared towards preserving environmental quality while trying to achieve a more sustainable agriculture development for the country in years to come.

CONCLUSION

In Malaysia, losses due to weeds in the plantation are moderately high (1). At present, herbicides are used to control weeds but the cost of chemical control is rapidly escalating. The present trend is towards the use of cost effective herbicides which have low toxicity to a particular ecosystem and the environment at large. Those herbicides which contribute to minimal pollution to soil, water and harvested products will be strongly recommended. There is an urgent need to cut back on the number of spraying rounds and rely more on selective spot-spraying for particular noxious weeds. In this way a beneficial ground cover can be finally obtained especially in the plantations.

An integrated management system involving the use of cultural methods, herbicides, grazing sheep and biological agents (insects) is highly recommended to reduce problems associated with weed infestations in plantations. Good cultural practices such as the use of minimal and proper timing of tillage, legume covers, intercropping and manuring will be encouraged (4, 5). The use of vigorous and high yielding clones or cultivars and advanced planting materials are to be stressed as this will reduce the period of immaturity and thereby reducing the number of spraying rounds for weed control in rubber and oil palm (6). In rice, emphasis is now given on proper water management and improvement of crop establishment in direct seeding to reduce weed problems (3).

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HONEY LOCUST *(GLEDITSIA TRIACANTHOS)* AND ITS CONTROL

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Summary. Practical control measures for honey locust (*Gleditsia triacanthos*) were investigated near Clifton on the Eastern Darling Downs and Toogoolawah in the Brisbane Valley in South East Queensland. Basal bark spraying with fluroxypyr as the methyl heptyl ester (Starane) at 3 g/L of diesel for basal diameters up to 10 cm, at 6 g/L for stem diameters of 10 to 20 cm and at 10 g/L for trunks greater than 20 cm in diameter at their bases gave the most consistent control. Foliar spraying with fluroxypyr at 1 g/L of water when actively growing gave effective control of seedlings and regrowth to 2 m tall. These findings have been used to obtain Agricultural Requirements Board approval for using fluroxypyr in a new initiative scheme of progressively controlling honey locust throughout Queensland.

INTRODUCTION

Honey locust (*Gleditsia triacanthos* L., Caesalpiniaceae), was introduced from North America and cultivated at Camden Park, New South Wales along with three other *Gleditsia* species as early as 1843(2). Honey locust has been widely promoted as an ornamental, fodder (1), shade and bee keepers' tree with its first reported planting in Queensland being in 1907(3).

It is a deciduous leguminous tree growing up to 24 m tall and bearing prolific green bipinnate leaves ca. 10 cm long, from spring to autumn. In spring it bears creamy, yellow pendulous flower spikes ca. 10 cm long which develop into 30 cm or so long brown pods. Some varieties have separate male and female plants, while cv. *inermis* has been developed, sold and planted as a thornless type. Naturalized offspring develop formidable (up to 25 cm long) trifid (crucifix like) spines along trunks and branches especially after pruning, cutting or grazing (Fig. 1).

Honey locust's pods are sweet and are relished by livestock which spread its seeds in their dung. Seedlings quickly grow a strong tap-root and dominate surrounding vegetation. Flood waters also transport the floating pods, causing major infestations of dense thorny thickets along the fertile alluvial flood plains from Southern Australia (5) to north of Monto (latitude 24ºS) in Central Queensland. Its potential for spread over large areas is enormous, as it grows naturally from Mexico to Ontario (latitude 26º to 50ºN) (3) (Fig. 2).

Following the first infestation reported to Queensland Lands Department in 1955 along Cressbrook Creek, a survey revealed it present along the Brisbane River, and in the Killarney, Maryvale and Warwick districts. Control trials resulted in a 1959 endorsement by the Co-ordinating Board (precursor of the Rural Lands Protection Board) of a Weeds Committee recommendation 'That all Local Authorities in South East Queensland be requested to destroy infestations on roads and reserves and to encourage landholders to take similar action on their holdings' (4). Since that time public, resumed and ungrazed land has become more densely infested to the detriment of the native vegetation and wildlife (3). Fire and/or dozing kills plant tops but produces massive regrowth from their bases unless deeply ploughed and regularly cropped.

Gleditsia triacanthos was declared a P2 category plant following a detailed submission in 1992 (5), which means it must be destroyed.

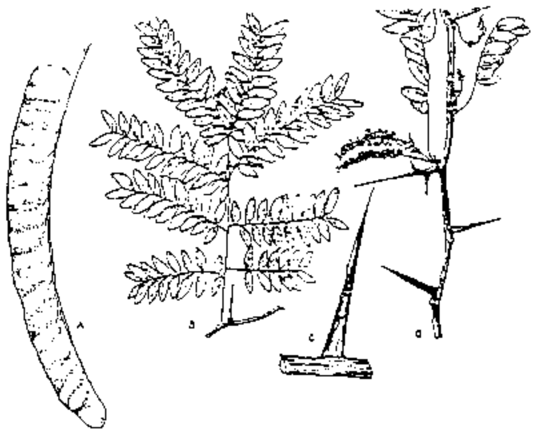

Figure 1. Honey locust (*Gleditsia triacanthos*).

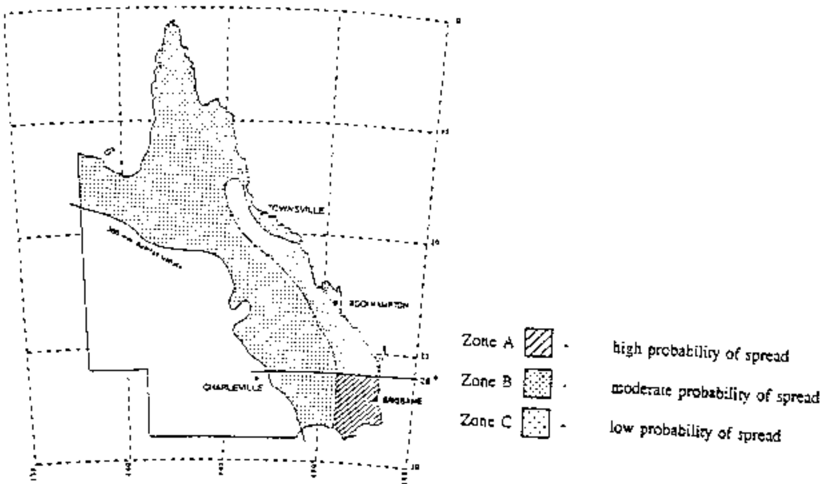

Figure 2. Potential distribution of Honey locust in Queensland.

METHODS

Control experiments have been set out progressively since the 1950s in Queensland as new methods and herbicides became available (8). With the loss of 2,4,5-T and requests for alternative controls of honey locust, a series of experiments were set out along King Creek near Clifton from October 1989 to January 1990 (Table 1).

Table 1. Clifton application techniques, herbicides, rates and control as percentage kill of untreated *Gleditsia triacanthos*.

Date treated	Technique	Herbicide	Rate	Target type	Control % by 14/12/90
30/10/89	Basal Bark[a]	2,4,5-T ester	20 g/L Diesel	>10 m tall	100
11/01/90	Basal Bark	Triclopyr ester	10 g/L Diesel	>10 m tall	95
"	Cut Stump[b]	Triclopyr ester	10 g/L Diesel	<10 m tall	95
"	Over all spray[c]	Triclopyr ester	10 g/L Diesel	<1 m tall	95
"	Basal Bark	Fluroxypyr ester	10 g/L Diesel	>10 m tall	100
"	Cut Stump	Fluroxypyr ester	10 g/L Diesel	<10 m tall	100
"	Over all Spray	Fluroxypyr ester	10 g/L Diesel	<1 m tall	100
"	Stem inject[d]	Dicamba	200 g/L	>10 m tall	100
"	Stem inject	Picloram + Triclopyr amine	50 g + 100 g/L	>10 m tall	100
"	Stem inject	Clopyralid	300 g/L	>10 m tall	100
"	Stem inject	Glyphosate	450 g/L	>10 m tall	100
"	Stem inject	Hexazinone	250 g/L	>10 m tall	50
"	Stem inject	Metsulfuron methyl	6 g/L water	>10 m tall	95
12/01/90	Foliar Spray[e]	2,4-D amine + 'Pulse'	5 g/L + 2 mL/L water	<10 cm tall	100
"	Foliar Spray	Picloram + Triclopyr ester	0.35 g + 1.05 g/L water	<2 m tall	100
"	Foliar Spray	Fluroxypyr + Pulse	1.3 g/L + 2 mL/L water	<3 m tall	100
"	Foliar Spray	Clopyralid + Ethokem	1.3 g/L + 5 mL/L water	<1 m tall >1 m tall	100 50
"	Foliar Spray	metsulfuron methyl + Ethokem	6 g + 500 mL/100 L water	<2 m tall	50
"	Sprinkler Spray	Glyphosate + Ethokem	18 g + 10 mL/L water	<2 m tall	50
"	Checks	untreated	0	0-20 m tall	0

a. Basal Bark treatment of full circumference of each trunk to 40 cm above ground level.
b. Cut stump and immediately swab fresh sap.
c. Overall spray leaves and stems with knapsack sprayer.
d. Stem Inject with 1 mL/3 cm cut with <3 cm between cuts around circumference.
e. Foliar Spray all leaves to point of run-off at ca 2000 L/ha with knapsack sprayer.
f. Sprinkler Spray foliage with large droplets at ca.100 L/ha.

Following more interest and requests, further experiments were set out along Cressbrook Creek near Toogoolawah from December 1991 (Table 2).

Table 2. Toogoolawah application techniques, herbicides, rates and control as percentage kill of untreated *Gleditsia triacanthos*

Date treated	Technique	Herbicide	Rate	Target type	Control % by 8/10/92
17/12/91	Foliar Spray[i]	Glyphosate	3.6 g/L water	<2 m Regrowth	97
	Foliar Spray	2,4-D amine ± Surfactant	5 g/L ± 2 mL/L water	<2 m Regrowth	0
	Foliar Spray	2,4-D acid	3 g/L water	<2 m Regrowth	0
	Foliar Spray	2,4-D ester	2.4 g/L water	<2 m Regrowth	0
	Foliar Spray	Picloram + 2,4-D amine	0.5 g + 2 g/L water	<2 m Regrowth	80
	Foliar Spray	Picloram + Triclopyr ester	0.35 g + 1.05 g/L water	<2 m Regrowth	70
	Foliar Spray	Picloram + Triclopyr ester	2.1 g/L water	<2 m Regrowth	20
	Foliar Spray	Fluroxypyr ester	1 g/L water	<2 m Regrowth	99
	Foliar Spray	Clopyralid ± Surfactant	1.5 g ± 2 mL/L water	<2 m Regrowth	50
	Foliar Spray	Dicamba ± Surfactant	2 g ± 2 mL/L	<2 m Regrowth	50
08/01/92	Foliar Spray	Dichlorprop K salt	6 g/L water	<2 m Regrowth	20
	Foliar Spray	Dichlorprop acid	4 g/L water	<2 m Regrowth	20
	Foliar Spray	Amitrol-T ± Surfactant	5 g ± 2 mL/L water	<2 m Regrowth	0
	Foliar Spray	Imazapyr	10 g/L water	<2 m Regrowth	20
	Foliar Spray	Fluroxypyr ester	1.5 g/L water	<3 m Regrowth	99
09/01/92	Foliar Spray	Metsulfuron methyl + 'Bond'	15 g + 150 mL/100 L water	<3 m Regrowth	97
	Basal Bark[k]	Triclopyr ester	10 g/L Diesel	>20 cm Diameter	95
	Basal Bark	Fluroxypyr ester	10 g/L Diesel	>20 cm Diameter	99
05/02/92	Basal Bark	2,4-D ester	10 g/L Diesel	>20 cm Diameter	80
	Basal Bark	2,4-D ester	20 g/L Diesel	>20 cm Diameter	90
04/03/92	Basal Bark	Fluroxypyr ester	6 g/L Diesel	>10 cm Diameter	95
	Basal Bark	Fluroxypyr ester	5 g/L Diesel	10-20 cm Diameter	100
	Basal Bark	Diesel	Neat	<10 cm Diameter	100
	Foliar Spray	Fluroxypyr ester	0.75 g/L water	<3 m Regrowth	90
	Checks	Untreated	0	0-40 cm Diameter	0

i. Foliar Spray with 12 volt battery powered pump and brush gun at ca. 3000 L/ha.

k. Basal Bark spraying of full circumference of each trunk to at least same height as its diameter.

RESULTS AND DISCUSSION

Mature honey locust trees were difficult to stem inject due to numerous spines along their trunk and cuts greater than 3 cm apart allowing growth to continue. In dense situations the cut stump technique was only practical for trees less than 10 m tall. Basal bark spraying was the easiest and gave the best kills from the largest to the youngest trees, with the same diesel mixtures working as a cut stump or overall spray for young trees under 1 m tall. Trees less than 3 m tall were susceptible to foliar spraying with water based fluroxypyr (Starane) and picloram + triclopyr (Grazon). Seedlings not eaten by cattle were controlled by 2,4-D amine (Amicide 500), while plants up to 1 m tall were killed by clopyralid (Lontrel). Glyphosate (Roundup) as applied through a sprinkler sprayer and metsulfuron methyl (Brushoff) applied with a knapsack sprayer at Clifton (Table 1) were not as effective as treatments at Toogoolawah applied with a battery powered brush gun (Table 2).

Even though most of the honey locust on alluvial flats beside Cressbrook Creek was regrowth after dozing there was 90% or better control from foliar sprayed glyphosate (which was non-selective on pasture grasses), metsulfuron methyl at higher than normal rates, and fluroxypyr at 1 g/L of water. The latter was reformulated into Starane 200, which gave a more stable solution in diesel than the fluroxypyr at 300 g/L for reliable basal bark spraying of all sizes of honey locust.

As there is usually a wide range of sizes of honey locust to be controlled in the infested areas, it is most practical to use the basal bark rate for the largest trees present but to use less of the mixture for smaller trunks so long as the full circumference of each stem's base is treated to at least the same height above ground level as its diameter.

ACKNOWLEDGEMENTS

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AERIALLY APPLIED HERBICIDES SELECTIVELY CONTROL BITOU BUSH GROWING IN COMMUNITIES OF INDIGENOUS PLANTS ON SAND DUNES

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Summary. Bitou bush (*Chrysanthemoides monilifera* spp. *rotundata* (L.) T. Norl.) is a perennial South African shrub that was planted extensively during the 1950's and 1960's to stabilise coastal sand dunes in eastern Australia. By the late 1960's it was recognised as an invasive weed. Experiments in 1985-86 tested herbicides to control Bitou bush at Bherwerre Beach, in the (now) Jervis Bay National Park on the south coast of NSW, Australia. Six herbicides were applied by hand to assess their relative toxicity to Bitou bush and to seven native plant species which had been planted in the 1960's to stabilise the beach. Glyphosate (Roundup 36% a.i.) and metsulfuron methyl (Brush-off 60% a.i.) excelled. Bitou bush was most susceptible to the herbicides during and just after peak flowering (May through August), when the native species were least susceptible. These findings led to aerial application of Roundup® at 3, 6 or 9 L/ha or Brush-off® at 50, 100 or 150 g/ha in 60 L of water per ha during August 1989. All rates of both chemicals killed Bitou bush without harming the native plants. Experiments are continuing using lower herbicide rates.

INTRODUCTION

Bitou bush is a woody perennial native to South Africa. Weiss reviewed the records of occurrence of C. *monilifera* in various countries, including Australia (10). He concluded that information on the subspecies *rotundata* (Bitou bush) was vague, with the earliest records being for a specimen collected in the Stockton area near Newcastle, presumably from '*ballast dumped on the north bank of the Hunter River by South African ships. No other records exist until 1950 when a specimen was collected from the experimental area of the Soil Conservation Service of N.S.W. at Port Macquarie*'.

Weiss (10) continues '*Seed was sown extensively by the Soil Conservation Service of N.S.W. from 1946 to 1968 .... (and by companies extracting titanium from beach sands) from 1950 to 1970*'. As a consequence of these activities and of the natural mechanisms of propagation and dispersion, Bitou bush occurred along 660 km of the N.S.W. Coast and was dominant along 220 km, by 1982 (4). The density and extent of the infestation has not since been resurveyed; however, both are reputed to have increased substantially. This is consistent with an evaluation of the bioclimatic potential of Bitou bush (3). By the mid 1960's Bitou bush had been recognised as a threat to the flora and fauna of over 20 National Parks and Nature Reserves. Planting and seed distribution for stabilisation purposes ceased during the 1970's and investigation into control began. Control efforts were focussed from three directions. First, community groups were encouraged to recognise the plant and remove it. Secondly, a systematic search was commenced for biocontrol agents. Thirdly, the potential for selective chemical control was examined. This article is an account of part of the latter stream of research.

Between 1985 and 1989 we conducted two series of experiments using an LPG powered spraygun (8). The first series tested the relative selectivity of the herbicides Ciba-Geigy Code No. GGA-131036, dichloropicolinic acid (Lontrel), fosamine (Krenite), glyphosate (Roundup), metsulfuron methyl (Brush-off) and tricolpyr (Garlon) on Bitou bush, *Casuarina glauca, Leptospermum laevigatum, Leucopogon parviflorus, Acacia longifolia var. sophoral, Banksia integrifolia, Monotoca elliptica and Lomandra longifolia*. Only glyphosate and metsulfuron methyl proved sufficiently selective to warrant further study (6). Similar results were obtained by McMillan (5). The second series explored times and rates of herbicide application to maximise selectivity and minimise herbicide dose. This work is continuing, but by 1989 had progressed to the point where a window of opportunity had been demonstrated (7). This occurred in winter, after peak flowering of Bitou bush. Finally, Anderson reported successful control of Bitou bush, using 8 L of Roundup in 122 L of water per hectare from a helcopter, without damage to (unspecified) native vegetation (1). Armed with this information we undertook our first aerial herbicide applications in winter 1989.

METHODS

The site was at the northern end of Bherwerre Beach in the (now) Jervis Bay National Park. This beach had been destabilised by repeated grazing and burning over the previous 60 years. It was reshaped and stabilised during the 1960's. The species planted included: *Acacia longifolia var. sophorae, Banksia integrifolia, Leptospermum laevigatum, Leucopogen parviflorus, Lomandra longifolia, Monotoca elliptica*, and (~ 300 tubestock of) Bitou bush. Despite attempts to contain the Bitou bush infestation by hand spraying with herbicides, Bitou bush had become the dominant species over much of the 7 km of the beach by 1989 and was invading adjacent woodland.

The treatments were four rates of glyphosate applied as Roundup (36% a.i.) at 0, 3, 6 and 9 L/ha and three rates of metsulfuron methyl applied as Brush-off (60% a.i.) at 50, 100 and 150 g/ha. The latter treatments were applied with nonionic wetter (BS 1000) at 1 mL/L and the 50 and 150 g/ha rates were repeated without wetter. All treatments were applied in 60 L of water per hectare using conventional spray nozzles fitted to a boom attached to a helicopter flying at ~ 100 km/hr.

Each treatment was a single swath (~ 11 m wide and 280 m long). Treatments were separated by buffer strips (~ 19 m wide and 280 m long). Treatments were replicated twice and randomised within each of the two blocks. The buffer strip between blocks was ~ 38 m wide and 280 m long, resulting in an experimental area ~ 520 m x 280 m.

Before the treatments were applied we tagged eight individual plants per plot of each of the seven plant species that had been used to stabilise the beach. The tagged plants were scored for herbicide damage to the foliage (0 = no damage, 10 = foliage completely desiccated) during the following 12 months.

RESULTS AND DISCUSSION

Bitou bush. Bitou bush was more sensitive to both herbicides than anticipated from the results of hand spraying, with the lowest rates of both aerially applied herbicides causing very high mortality (Table 1). Consequently, the enhancement of metsulfuron methyl toxicity expected from the addition of wetting agent was evident only at the first time after spraying and then only at the lowest herbicide rate (Table 1).

Table 1. Bitou bush response to herbicides applied from the air in 60 L of water per hectare during Winter 1989

Herbicide treatment			Time after application (months)			
			0	2.5	5	7
Compound	Rate		Foliar damage score[1]			
Roundup	0 L/ha		0	0	0	0
(36% a.i.)	3 L/ha		0	9.7	9.9	9.9
	6 L/ha		0	9.9	10	10
	9 L/ha		0	10	10	10
Brush-off	50 g/ha	- wetter[2]	0	8.4	10	10
(60% a.i.)		+ wetter[2]	0	9.0	10	10
	100 g/ha	+ wetter[2]	0	9.7	10	10
	150 g/ha	- wetter[2]	0	9.5	10	10
		+ wetter[2]	0	9.6	10	10

[1] Scores of 0 and 10 equate to no damage and total desiccation of foliage respectively. Values are means for eight plants per replicate and two replicates per treatment.

[2] Wetter is BS 1000 at 1 mL/L of mixture.

We also recorded the number of Bitou bush seedlings in 50 cm x 50 cm fixed quadrats under the tagged Bitou bushes. Where glyphosate had been applied, there were >400 seedlings per square metre and the number was independent of the herbicide rate. This is consistent with low availability of glyphosate even from sandy soil (2). In contrast, metsulfuron methyl has a residual effect (9). This was evident as a depression in the seedling density to <200 plants per square metre, which lasted throughout the period of observation.

<u>Native plants</u>. It is conjectural whether the herbicides caused any measurable foliar damage to: *Acacia longifolia var. sophorae, Banksia integrifolia, Lomandra longifolia* and *Monotoca elliptica*. If any damage occurred it was ephemeral. Consequently data are not presented for these species. *Leptospermum laevigatum* and *Leucopogon parviflorus* were not affected by glyphosate and only slightly damaged by metsulfuron methyl (Table 2). Addition of wetting agent to metsulfuron methyl did not consistently modify its phytotoxicity, so we have presented averages for the $\pm$ wetting agent treatments (Table 2).

These results clearly demonstrate that Bitou bush can be killed using low doses of Roundup (3 L/ha) or Brush-off (50 g/ha) from the air in winter, without appreciable damage to the six native plant species studied. Experiments conducted in winter 1991 at Bherwerre Beach and in winter 1992 at two locations confirm these findings. Since none of the treatments failed to control Bitou bush, further reductions in herbicide rates should be possible.

The results also justify continued research on chemical control of Bitou bush. First, to assess the herbicide tolerance of a wider range of native plants and so establish the likely usefulness of aerial spraying against Bitou bush on sites supporting more diverse plant communities. Secondly, to assess the impacts of these herbicides in the dune environment. And thirdly, to facilitate integration of chemical and biological control strategies.

Table 2. Native plant species damaged by herbicides applied from the air in 60 L of water per hectare during Winter 1989

Herbicide treatment		Plant species	Time after application (months)			
			0	1.5	2.5	7
Compound	Rate		Foliar damage score[1]			
Roundup	0 L/ha	*Leptospermum*	0	0	0	0
(36% a.i.)	3 L/ha	*laevigatum*	0	0	0	0
	6 L/ha		0	0	0	0
	9 L/ha		0	0	0	0
Brush-off	50 g/ha ± wetter[2]		0	1.0	0.25	0
(60% a.i.)	100 g/ha + wetter[2]		0	2.0	1.0	0
	150 g/ha ± wetter[2]		0	2.0	1.0	0
Roundup	0 L/ha	*Leucopogon*	0	0	0	0
(36% a.i.)	3 L/ha	*parviflorus*	0	0	0	0
	6 L/ha		0	0	0	0
	9 L/ha		0	0	0	0
Brush-off	50 g/ha ± wetter[2]		0	1.8	1.0	0
(60% a.i.)	100 g/ha + wetter[2]		0	1.5	1.5	0
	150 g/ha ± wetter[2]		0	2.0	1.25	0

[1] Scores of 0 and 10 equate to no damage and total desiccation of foliage respectively. Values are means for eight plants per replicate and two replicates per treatment, except where the Brush-off data have been averaged across two wetter treatments.

[2] Wetter is BS 1000 at 1 mL/L of mixture.

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CONTROL OF *CLIDEMIA HIRTA* IN MATURE RUBBER AREAS

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Summary. Field trials were conducted under mature rubber trees to control *Clidemia hirta* by slashing and with herbicides. Triclopyr at 0.375 kg a.e./ha was more effective than slashing. Fluroxypyr at 0.4 kg a.e./ha and metsulfuron methyl at 0.02 kg a.i./ha plus a nonionic surfactant were effective. Mixtures of triclopyr with either fluroxypyr or metsulfuron methyl enhanced control of the weed but its mixture with the contact herbicides paraquat or sodium chlorate produced less persistent control. Addition of the adjuvants Ethokem, Polypol Ace, Lissapol and Bivert showed some improvement in control of the weed. Application of triclopyr at 0.25 kg a.e./ha using five different sizes of fan nozzles with their orifices ranging from 0.08 to 0.28 cm resulted with nonsignificant difference in control but triclopyr at 0.075% w/v applied using these nozzles produced decreasing weed control with decreasing nozzle sizes.

INTRODUCTION

Clidemia hirta, a woody shrub under the Melastomaceae family, is an important dicotyledonous weed found under mature rubber especially in the southern part of Peninsular Malaysia. It is usually about one meter high but can grow much taller. Once established, it can spread rapidly especially via seeds. Slashing causes shoots to regenerate from the basal stems. The seeds are small and are embedded in bluish black berries which are relished by birds which help to spread the weed. This weed is susceptible to a number of herbicides and some of these can provide persistent control. The herbicide 2,4,5-T was formerly recommended for controlling this weed (3) but due to its contamination with dioxin which is carcinogenic, alternative herbicides were sought. Subsequent to this, the herbicide triclopyr was found to be a suitable alternative to 2,4,5-T (10).

The objective of the trial was to determine the effectiveness of slashing, herbicides or herbicide mixtures in comparison to triclopyr on the control of *C. hirta*. It was also investigated whether weed control could be improved by adding adjuvants to triclopyr. Trials were also conducted to determine whether weed control is affected by variable orifice sizes of fan nozzles.

METHODS

Established stands of *C. hirta* of moderate to high density under mature rubber trees of about thirty years old in Sungai Buaya, Selangor were used. The height of the weed was mostly about three quarter to one meter high. The herbicides were sprayed using a knapsack sprayer fitted with a fan jet nozzle. The pressure of the pump was about three bars. The size of each plot was 20 m^2 and there were three or four replicates for each treatment. The soil was sandy clay loam.

Weed control was assessed visually based on a 0 to 100 rating system where 0 = 0% kill and 100 = 100% kill of the weed at about monthly intervals. The data were transformed to arcsin $\sqrt{\text{percentage}}$ for statistical analysis.

The herbicides used were Garlon 250 (triclopyr, butoxy ethyl ester - 32.1% w/w), Tordon 101 (2,4-D triisopropanol amine salt - 39.6% w/w + picloram triisopropanol amine salt - 10.2%

w/w), Starane 200 (fluroxypyr, 1-methyl heptyl ester - 29.64% w/w), Ally 20DF (metsulfuron methyl - 20% w/w), Gramoxone PP910 (paraquat dichloride - 25.3% w/w) and Ancom Sodium chlorate (sodium chlorate - 99% w/w).

Effect of slashing and herbicides. Slashing using a motorised slasher was compared to the herbicides triclopyr (0.375 and 0.75 kg a.e./ha) and picloram + 2,4-D (0.2 + 0.7 and 0.3 + 1.2 kg a.e./ha). Different rates of triclopyr ranging from 0.125 to 0.625 kg a.e./ha was also evaluated. The more recent herbicides, fluroxypyr and metsulfuron methyl, were also evaluated. The rates of fluroxypyr were 0.1 to 0.6 kg a.e./ha while metsulfuron methyl were from 0.02 to 0.1 kg a.i./ha. Du Pont Agricultural surfactant which is a nonionic surfactant was also added to metsulfuron methyl.

Evaluation of triclopyr mixtures. Mixtures of triclopyr with either fluroxypyr, metsulfuron methyl, paraquat or sodium chlorate were evaluated in order to determine whether imrovement in weed control could be obtained.

Evaluation of adjuvants. The ability of selected adjuvants to improve the effectiveness of triclopyr was evaluated. The effectiveness of triclopyr at 0.25 kg a.e./ha mixed with either the cationic surfactants Ethokem (fatty amine ethoxylate) or Hyspray 52 (polyethoxylated amine), a nonionic surfactant Polypol Ace (nonylphenol polyethylene glycol ether) or Lissapol (sodium oleyl ceyl sulphate) or with an adjuvant Bivert (amine salts of organic acids, aromatic acid, aromatic and aliphatic petroleum distillate) was also evaluated.

Evaluation of fan nozzles. Triclopyr at 0.25 kg a.e./ha was sprayed using fan nozzles with nozzle orifices of 0.08, 0.12, 0.16, 0.2 and 0.28 cm which delivered about 100, 130, 300, 500 and 600 L/ha of water respectively.

In another trial, triclopyr at a fixed concentration of 0.075 % w/v of the active ingredient per unit area was evaluated with similar sizes of fan nozzles.

RESULTS AND DISCUSSION

Effect of slashing and herbicides. Slashing was only effective initially as shoot regeneration from the living stems was relatively rapid (Fig. 1). Picloram + 2,4-D at 0.2 + 0.7 or 0.3 + 1.2 kg a.e./ha did not give good control of the weed but was more effective than slashing. Triclopyr at 0.375 and 0.75 kg a.e./ha were significantly more effective than picloram + 2,4-D and slashing. Teoh *et al.* reported that triclopyr was effective on *C. hirta* at 0.7 and 1.4 kg a.e./ha (7). The present trial, however, showed that a lower rate of triclopyr was sufficient to give good control of the weed. Yeoh and Faiz also reported on the efficacy of triclopyr but the rates used were slightly higher (10).

Increasing the rates of triclopyr increased control. Good control was achieved with triclopyr at 0.375, 0.5 and 0.625 kg a.e./ha. Regeneration of the weed was slow and at 36 weeks after treatment, triclopyr at 0.375 kg a.e./ha produced about 70% control while at 0.5 kg a.e./ha and at 0.625 kg a.e./ha, about 90% control was achieved. At least 0.375 kg a.e./ha of triclopyr was necessary to obtain effective control of the weed. Abu Bakar and Abu Bakar reported that triclopyr at rates of 0.45 to 0.75 kg a.e./ha were effective (1).

Fluroxypyr at 0.3 kg a.e./ha or more produced more than 90% control. At 30 weeks after treatment, fluroxypyr at 0.3, 0.4, 0.5 and 0.6 kg a.e./ha still showed more than 90% control. The efficacy of fluroxypyr on perennial broad-leaved weeds had been reported by Lee and Liao and they suggested rates of 0.25-0.5 kg a.e./ha for effective control (5).

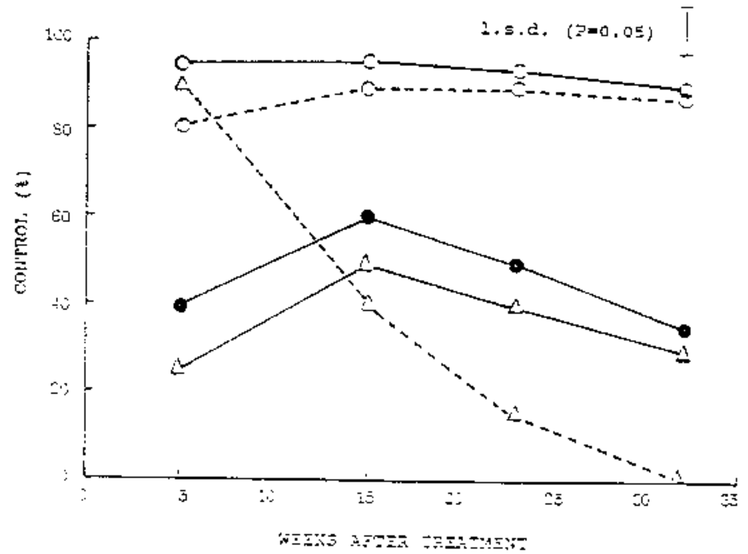

Figure 1. Effect of slashing (△---△) versus triclopyr at 0.375 kg a.e./ha (O---O) or 0.75 kg a.e./ha (O—O) and picloram + 2,4-D at 0.2 + 0.7 kg a.e./ha (△—△) or 0.3 + 1.2 kg a.e./ha (●—●) on control of *C. hirta*.

Metsulfuron methyl was also effective and more than 90% control was still obtained at 29 weeks after treatment with the herbicide at 0.04 to 0.1 kg a.i./ha. The results thus agree with Ackerson and Davis who reported on the efficacy of this herbicide on brush species in plantation crops (2). Earlier, Christie and Cornwell also reported on the effectiveness of this herbicide on broad-leaved weeds in cereals (4).

Efficacy of triclopyr mixtures. Triclopyr mixed with fluroxypyr produced enhanced and significantly more persistent control of the weed compared to the individual herbicide alone. More than 90% control was still obtained at 32 weeks after treatment with these mixtures.

Mixing triclopyr with metsulfuron methyl also improved weed control. Increasing control was obtained with increasing rates of metsulfuron methyl in the mixtures. Control was also more persistent with the herbicide mixtures compared to the individual herbicide treatment.

Mixtures of triclopyr at 0.25 kg a.e./ha with the contact herbicide paraquat at either 0.2 or 0.3 kg a.i./ha or with $NaClO_3$ at either 10 or 15 kg a.i./ha showed significantly less persistent control compared to triclopyr alone. Reduction in control could be attributed to the death of the weed tissues caused by the contact herbicides which prevented further translocation of triclopyr which is a systemic herbicide. Increasing rates of paraquat or $NaClO_3$ in the respective mixtures, however, showed slight enhancement in weed control.

Evaluation of adjuvants. The effectiveness of triclopyr at 0.25 kg a.e./ha was reduced when mixed with Hyspray 52, slightly improved with Ethokem, and was significantly better when mixed with Polypol Ace at 1.0 L/ha respectively. However, these treatments were significantly less effective than triclopyr at 0.375 kg a.e./ha. Improvement of triclopyr activity by Ethokem had also been reported by Prasad on forest weed species (6).

Addition of the nonionic surfactant Lissapol to triclopyr (0.25 kg a.e./ha) enhanced control of the weed significantly and increasing the rate of Lissapol also increased weed control. Wongwattana and Suwanketnikom had also reported on improved activity of triclopyr when added with a nonionic surfactant. They also found that the nonionic surfactant was also more effective than the anionic surfactant which they tested (9). The addition of the adjuvant Bivert at 0.5 L/ha did not improve triclopyr activity. However, control was slightly improved by the higher rate of Bivert at 1.0 L/ha. Mixture of triclopyr at 0.25 kg a.e./ha with Lissapol plus Bivert each at 0.5 L/ha respectively showed significant improvement in weed control.

Evaluation of fan nozzles. The different sizes of fan nozzles used to spray triclopyr at 0.25 kg a.e./ha did not produce significant differences in control. This indicated that the different volume rate of water applied did not affect the performance of triclopyr. Thomas *et al.* (1988), however, reported that a high carrier volume application generally was more effective and they attributed the improvement in control to better penetration of the dense weed in their trials.

On the contrary, a fixed concentration of triclopyr at 0.075% w/v applied using these fan nozzles produced decreasing weed control with decreasing nozzle sizes (Table 1). This is due to the lower active ingredient per unit area being delivered with the decreasing volume of water.

Table 1. Effect of triclopyr at 0.75% w/v on *C. hirta* using different sizes of fan nozzles

Nozzle size (cm)	Mean % control		
	8 weeks	12 weeks	25 weeks
0.08	70	63	30
0.12	75	70	38
0.16	80	75	55
0.20	98	88	85
0.28	98	95	80
l.s.d. (P=0.05)	5.4	7.7	4.8

CONCLUSIONS

Slashing was less effective than triclopyr at 0.375 kg a.e./ha and picloram + 2,4-D at 0.2 + 0.7 or 0.3 + 1.2 kg a.e./ha. Fluroxypyr at 0.4 kg a.e./ha and metsulfuron methyl at 0.02 kg a.i./ha plus a nonionic surfactant were effective. Mixtures of triclopyr with either fluroxypyr or metsulfuron methyl improved weed control but mixtures of triclopyr with the contact herbicides paraquat or sodium chlorate resulted in less persistent control. Addition of the adjuvants Ethokem, Polypol Ace, Lissapol and Bivert showed some improvement in control. Application of triclopyr at 0.25 kg a.e./ha using fan nozzles with their orifices ranging from 0.08 to 0.28 cm resulted in almost comparable control. Application of triclopyr at 0.075 % w/v with these nozzles, however, produced decreasing weed control with decreasing nozzle orifices.

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REPLACEMENT OF *LUDWIGIA PERUVIANA* WITH NATIVE PLANTS USING HERBICIDES IN AN URBAN WETLAND

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Summary. The use of herbicides to control *Ludwigia peruviana* was investigated in the Botany Wetlands, a series of shallow urban lakes in the Sydney metropolitan area. Field trials over two years evaluated five herbicides registered for aquatic use. Glyphosate and 2,4-D amine (diethylamine salt) gave best control. Application in April-May was most effective but earlier treatment improved selectivity of several desirable species, notably *Typha* spp. and *Persicaria strigosa*. Other effective herbicides were dicamba, picloram/2,4-D, fluroxypyr, imazapyr and triclopyr when applied in January and May. They offered little advantage over glyphosate or 2,4-D.

INTRODUCTION

Ludwigia peruviana is a shrub-like plant that was introduced to Sydney in 1907 as a botanical specimen (1). It was recorded as naturalised in the Botany Wetlands in 1970 (although it was growing there before this date) and currently forms dense dominant stands over about 21 ha of the total area. *L. peruviana* is deciduous, seeds prolifically, thrives in shallow water or waterlogged areas and can grow up to 3 m tall (2, 3).

Restoration of the wetlands requires the removal of *L. peruviana* and its replacement with native species. Seven field trials were established to investigate the efficacy of herbicides for controlling *L. peruviana*, while minimising damage to native species.

METHODS

Two groups of compounds, registered aquatic herbicides and registered non-aquatic herbicides (Table 1), were evaluated in replicated randomised plot field trials. Plot size varied from 3x5 m to 30x8 m and plant stands were 2-3 m tall.

Herbicide application was made using an adjustable hollow cone nozzle attached to a 2.5 m hand lance connected to a 9 L back-mounted tank, pressurised by LPG gas to give a spraying pressure of 250-300 kPa. Spraying was done from the shore, penetration of foliage being obtained by altering nozzle pattern and angle. Volumes of application were to point of run-off, and ranged from 650-1875 L/ha.

Timing of application varied from mid-January through to mid-May (mid to late growing season) except for one trial where application was made in late August just as plant dormancy was breaking.

Table 1. Treatments used

Herbicide	Formulation	Rate a.i. (% w/v)	Wetter (% product)
Registered Aquatic Herbicides			
amitrole	250 g/L	0.10	Agral 600 (0.2)
amitrole + 2,2 DPA	250 g/L +740 g/kg	0.10 +0.33	Agral 600 (0.2)
dichlobenil	67.5 g/kg	15.0 (kg/ha)	-
diquat	200 g/L	0.10	Agral 600 (0.2)
glyphosate	360 g/L	0.36	-
"	"	0.54	-
"	"	0.36	Pulse (0.2)
"	"	0.54	Pulse (0.2)
2,4-D amine*	500 g/L	0.50	Agral 600 (0.2)
Registered Non-Aquatic Herbicides			
clopyralid	300 g/L	0.09	Agral 600 (0.2)
"	"	0.18	Agral 600 (0.2)
dicamba	200 g/L	0.10	-
"	"	0.20	-
fluroxypyr	300 g/L	0.09	-
"	"	0.18	-
imazapyr	250 g/L	0.13	-
"	"	0.25	-
metsulfuron	600 g/kg	0.001	Agral 600 (0.2)
picloram/2,4-D**	50/200 g/L	0.13	Agral 600 (0.2)
"	"	0.25	Agral 600 (0.2)
triclopyr	480 g/L	0.14	-
"	"	0.29	-

* diethylamine salt

** tri-isopropanol amine salt

RESULTS AND DISCUSSION

Registered aquatic herbicides (Table 2)

Amitrole alone and in mixture with 2,2 DPA, and dichlobenil, gave poor control. Dichlobenil activity may have been inhibited by the deep black fluffy benthos built up from urban run-off.

Diquat produced rapid and complete knockdown including extensive cane damage. However despite a second application at 62 DAT (days after treatment) the plants regrew to pre-treatment density from basal stem material.

Table 2. Phytotoxicity scores (mean) for all trials.

		91-051 (3R) 11 MAT		91-052 (2R) 9 MAT		92-066 (2R) 10 MAT		91-057 (3R) 5 MAT		92-067 (3R) 10 MAT		92-071 (2R) 7 MAT		92-069 (2R) 9 MAT	
Herbicide	% w/v ai	phyto	c.v.	phyto	c.v.	phyto	c.v.	phyto	c.v.	phyto	c.v.	phyto	c.v.	phyto	c.v.
<u>Registered Aquatic Herbicides</u>															
amitrole	0.10	23	138.0	-		-		-		-		-		-	
amitrole + 2,2 DPA	0.10 + 0.33	7	87.0	-		-		-		-		-		-	
dichlobenil	15.0 (kg/ha)	7	87.0	-		-		-		-		-		-	
diquat	0.10	12	65.0	-		-		-		-		-		-	
glyphosate	0.36	93	11.5	99	0.7	95	0.0	33	45.8	99	0	100	0	-	
"	0.54	83	35.0	99	0.7	94	6.0	-		-		-		-	
" / Pulse	0.36 / 0.2	95	9.0	-		-		-		-		-		-	
" / Pulse	0.54 / 0.2	100	0.0	-		-		-		-		-		-	
2,4-D	0.50	43	104.0	35	60.5	78	32.0	27	21.7	-		-		-	
"	0.67	-	-	-	-	97	2.2	-		-		-		-	
Registered Non-Aquatic Herbicides															
clopyralid	0.09	-	-	-		-		-		7	173.0	-		-	
"	0.18	-	-	-		-		-		0	0.0	-		-	
dicamba	0.10	-	-	-		-		-		48	59.0	-		-	
"	0.20	-	-	-		-		-		78	22.0	-		-	
fluroxypyr	0.09	-	-	-		-		-		81	24.0	99	0.7	-	
"	0.18	-	-	-		-		-		90	6.0	99	0.7	-	
imazapyr	0.13	-	-	-		-		-		99	0.6	-		-	
"	0.25	-	-	-		-		-		100	0.6	-		-	
metsulfuron	0.001	-	-	5	141.0	-		-		32	55.0	-		-	
picloram/2,4-D	0.13	-	-	-		-		-		96	2.0	-		-	
"	0.25	-	-	-		-		-		99	0.6	-		-	
triclopyr	0.14	-	-	-		-		-		70	29.0	93	4.0	95	0
"	0.29	-	-	-		-		-		97	3.0	98	0	95	0
Untreated	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

MAT - Months after treatmentDAT - days after treatment
c.v. Coefficient of variation %(-R) - Number of replicates
Phytotoxicity - % visual phytotoxicity score 0-100% linear scale

Aquatic weeds

Glyphosate alone at 0.36% w/v gave almost complete control and was equal to the higher rate of 0.54% when applied between January and May (summer-autumn). Trial 91-057 applied in August (late winter-early spring) gave poor control. The high rate of glyphosate (0.54% w/v) with Pulse adjuvant gave complete kill with one application in small plots. On a large scale re-treatment would be necessary to control seedling growth and two applications of glyphosate alone at the lower rate (0.36% w/v) would probably give the same result as using higher rates with Pulse. It would also be cheaper as well as reducing the potential contamination.

2,4-D gave initial control equal to glyphosate but erratic regrowth occurred. One re-treatment would probably give complete control.

<u>Registered non-aquatic herbicides</u> (Table 2)

Metsulfuron and clopyralid gave poor control and treated plants recovered readily. Dicamba was not quite as effective as 2,4-D, and was more expensive.

Fluroxypyr, imazapyr, picloram/2,4-D and triclopyr all gave excellent control when applied in January. Fluroxypyr and triclopyr gave slightly improved control when applied in May (autumn). Triclopyr has excellent aquatic toxicology, short half life in water and useful selectivity (registration is pending in the USA) thus it offers good potential for use in the Botany Wetlands.

<u>Selectivity</u>

Further work is planned to more clearly define selectivity for native plants. Observations to date indicate 2,4-D had strong selectivity to grasses, a useful species in steep sandy shore line areas prone to erosion. At the water line *Persicaria strigosa* recovered rapidly and *Typha* was tolerant to 2,4-D.

Glyphosate is most effective when applied in autumn on *L. peruviana*. The protective effect of *L. peruviana* should ensure reasonable survival of *Typha* which usually rapidly re-establishes. Re-treatment with an alternative herbicide such as 2,4-D is proposed in areas where *Typha* is desirable.

Observations on single plants indicated that *Schoenoplectus validus, Acacia longifolia, Kunzea ambigua* and *Triglochin procerum* can tolerate partial treatment with glyphosate. *Hydrocotyle bonariensis* and *Persicaria strigosa* were initially desiccated but regenerated readily.

With triclopyr good selectivity was noted to the grasses *Paspalum urvillei, Eragrostis curvula* and *Pennisetum clandestinum*. Other species that were tolerant or recovered included *Typha, Eleocharis sphacelata* and *Hydrocotyle bonariensis*. Triclopyr and 2,4-D show similar selectivity.

ACKNOWLEDGMENTS

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SONCHUS OLERACEUS RESISTANT TO THE ALS INHIBITING HERBICIDES

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Summary. A biotype of *Sonchus oleraceus* from Goondiwindi, Queensland, is the first dicot species in Australia resistant to ALS inhibiting herbicides. This biotype was selected for 8 years with chlorsulfuron and is resistant to chlorsulfuron and a wide range of other sulfonylurea and imidazolinone herbicides. The LD_{50} ratios for the resistant biotype are at least 60-fold greater for sulfonylureas and at least 4.5-fold greater for imidazolinones than for susceptible *S. oleraceus*. GR_{50} ratios are greater than 9-fold for sulfonylureas and 7.4-fold for imazapyr. The resistant biotype is not resistant to non-ALS inhibiting herbicides. This paper documents the dose response of the resistant *S. oleraceus* to a range of herbicides.

INTRODUCTION

Sonchus oleraceus is an annual weed present in all states of Australia and widespread in the temperate zones of both hemispheres (1). It can be a serious problem in the northern Australian cereal cropping zone.

Acetolactate synthase (ALS, also know as acetohydroxyacid synthase, or AHAS) catalyses the first reaction in the production of three branched chain amino acids, leucine, isoleucine and valine (2). This biosynthetic pathway is only found in microbes and higher plants. There are several classes of herbicides that inhibit ALS. Chlorsulfuron was the first ALS inhibitor herbicide in the sulfonylurea class, commercialised in 1982. Imidazolinone, triazolopyrimidine and pyrimidinyl thiobenzoates are three other herbicide classes that directly inhibit ALS activity (reviewed in 3).

In Australia, sulfonylureas are the most widely and frequently used herbicides throughout the cereal cropping zone, particularly chlorsulfuron and triasulfuron for control of *Lolium rigidum* (annual ryegrass) and many broadleaf weeds in cereals. To add to the selection pressure imposed by ALS inhibitors, the imidazolinone herbicide, imazethapyr, and two triazolopyrimidine herbicides, flumetsulam and metsulam are being marketed. These imidazolinone and triazolopyrimidine herbicides are recommended for weed control in some dicot crops. Until recently these crops were an important break from sulfonylureas, but now there will be an ALS-inhibitor herbicide that could be used in each part of the cereal-legume rotation. This can only lead to a higher selection pressure imposed on all susceptible weed species.

In North America, eight dicot and two grass weeds have developed resistance to ALS inhibitors (reviewed in 3). In contrast, until now annual ryegrass has been the only weed to develop resistance to the ALS inhibitors in Australia (4, 5). However, our current work reveals that biotypes of three dicot weeds, *S. oleraceus*, *Sisymbrium orientale* and *Brassica tournefortii*, have developed resistance to the ALS inhibitors following selection with sulfonylurea herbicides. This study reports the first broadleaf weed in Australia, *S. oleraceus*, to become resistant to ALS inhibitors.

METHODS

Plant material. Seed of *S. oleraceus* was collected in the summer of 1991 from a wheat field near Goondiwindi in which chlorsulfuron had failed to control this species. In this field chlorsulfuron was applied between 10.5 and 12.75 g a.i./ha, either pre- or post-emergent consecutively for 8 years. Hereinafter this population is referred to as the resistant biotype. Susceptible seed (hereinafter referred to as the susceptible biotype) was collected from the Waite Institute from a paddock which had never been treated with an ALS inhibitor.

Pot experiments. Seeds were germinated on 0.6% agar in a seed incubator. After five days, seedlings were transplanted into 17 cm pots outside. When at the 3-4 leaf stage, the plants were sprayed in a precision herbicide spray cabinet. Both biotypes were tested post-emergent with six ALS inhibitor herbicides and five herbicides with different modes of action. There were five replicates (pots) per rate and seven rates per herbicide. The herbicides tested were chlorsulfuron, sulfometuron, metsulfuron, imazapyr, flumetsulam, bromoxynil, diuron, metribuzin, MCPA and diflufenican. Surfactant (0.2% (v/v) Agral 600®) was applied with each herbicide.

After herbicide application, the plants were returned to the field and organised in a completely randomised design. Thirty days after spraying, survival was recorded and dry weight 48 h later. The experiment was repeated and the data pooled for analysis.

RESULTS AND DISCUSSION

Resistance to ALS inhibitors. The pot studies confirmed the field failure of chlorsulfuron in that the *S. oleraceus* biotype is highly resistant to this herbicide. Susceptible plants were killed with 2.5 g a.i./ha whereas doses above 67.5 g a.i./ha chlorsulfuron were required to kill resistant plants (Fig. 1a). Although the difference in dry weight response between the resistant and susceptible biotypes was not as large as the difference in plant survival to chlorsulfuron, the difference was still significant (Fig. 1a and 1b). The large difference in response to chlorsulfuron between both biotypes is further exhibited by the R/S [a]LD_{50} ratio, being greater than 86 (Table 1) and the R/S [a]GR_{50} greater than 28 (Table 1). This *S. oleraceus* biotype was also tested with two other sulfonylureas and found to be highly resistant (Table 1). Very similar GR_{50} ratios have been recorded for *Kochia scoparia* in North America (6). However, for resistant biotypes of *Stellaria media*, *Lolium perenne* and *Salsola iberica* higher GR_{50} ratios were recorded suggesting that plant growth reduction was not as sensitive to these sulfonylurea herbicides as for this *S. oleraceus* biotype (7).

The finding that the *S. oleraceus* biotype is highly resistant to sulfometuron-methyl (Table 1) indicates that the mechanism of resistance to the ALS inhibitors may be a mutant form of the ALS enzyme, as has been documented for all dicot weed species that have developed resistance to the ALS inhibitors in North America (3). This indication is based on work that has shown that sulfometuron-methyl metabolism is very slow, even in species that rapidly metabolise other sulfonylureas such as wheat (8, 9). In light of such findings, because the *S. oleraceus* biotype is highly resistant to sulfometuron, then resistance is unlikely metabolism based, but most likely due to a mutant ALS enzyme. Enzyme assays have not yet been performed.

The *S. oleraceus* biotype is less resistant to imidazolinone herbicides. This is illustrated by the LD_{50} ratios which are at least 10-fold greater for the sulfonylurea herbicides (Table 1). The GR_{50} ratio of the resistant *S. oleraceus* falls within the published results of the GR_{50} ratios of three ALS target-site mutant resistant weed species; the GR_{50} ratio of *S. media* was 8-fold greater, *L. perenne* 600-fold greater and *S. iberica* 2.5-fold less (7).

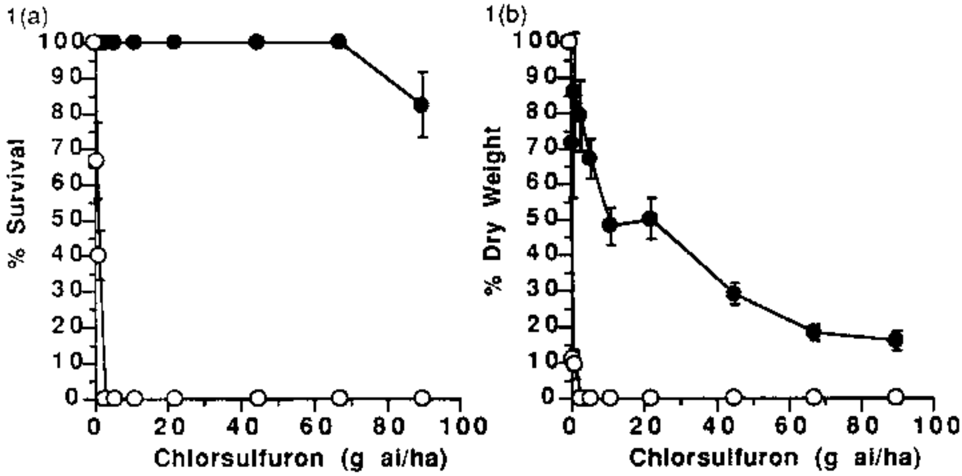

Figure 1. (a) Percent survival and (b) percent dry weight of susceptible (○) and resistant (●) *S. oleraceus* to chlorsulfuron 30 days after treatment. Each point is the mean of 5 replicates repeated twice. Error bars show the standard error of the mean for that rate.

Table 1. LD_{50} and GR_{50} measurements for resistant and susceptible *S. oleraceus* treated with 11 herbicides

Herbicide	LD_{50} (g a.i./ha)			GR_{50} (g a.i./ha)		
	R	S	R/S ratio	R	S	**R/S ratio**
Sulfometuron	>120	<0.94	>128	26.3	<0.94	**>28**
Chlorsulfuron	>90	1.1	>82	16.6	<0.71	**>23**
Metsulfuron	>24	<0.38	>63	3.3	<0.38	**>9**
Imazapyr	142	17	8.4	32.7	4.4	**7.4**
Imazethapyr	467	105	4.5	-	-	-
Flumetsulam	>160	>160		>160	>160	
Metribuzin	31.6	29.7	1.1	25.6	33.9	**0.8**
Diuron	24.8	35.7	0.7	15	29.1	**0.5**
Bromoxynil	8.9	8.1	1.1	-	-	-
Diflufenican	52.1	46	1.1	13	17.5	**0.7**
MCPA	275	256	1.1	77	87	**0.9**

* LD_{50} is defined as the rate of herbicide application in grams active ingredient/hectare (g a.i./ha) required to kill 50% of the population.

* GR_{50} is defined as the rate of herbicide application in g a.i./ha required to inhibit plant growth by 50% relative to untreated controls.

Flumetsulam had no activity on either *S. oleraceus* biotype. This finding is consistent with technical information supplied by Dow Elanco. In contrast, susceptible *S. media* was sensitive to DE-489 another triazolopyrimidine, whereas the chlorsulfuron resistant *S. media* biotype was cross-resistant to DE-489 (10). It will be interesting to test if ALS from *S. oleraceus* is inhibited by flumetsulam.

Both *S. oleraceus* biotypes were equally sensitive to herbicides with modes of action different from ALS inhibitors (Table 1). This response was also documented for resistant and susceptible *K. scoparia*, tested with bromoxynil, MCPA and diuron (6). Therefore, as for the North American ALS inhibitor resistant dicot weed species the resistant *S. oleraceus* does not show any cross resistance to non-ALS inhibitor herbicides.

CONCLUSION

This study documents the first dicot weed species, *S. oleraceus* resistant to the ALS inhibiting herbicides in Australia. This biotype is highly resistant to the sulfonylurea herbicides, similar to the ALS inhibitor resistant dicot weeds of North America and is resistant, but less so, to the imidazolinone herbicides. Early indications suggest that resistance is probably due to a mutated ALS enzyme, although this has not yet been confirmed. Current studies have recently confirmed two other dicot species as highly resistant to sulfonylureas. There seems little doubt that other weed species will develop resistance to the ALS inhibitor herbicides. Given the widespread usage of sulfonylureas and the introduction of new ALS inhibitors it is inevitable that further species will develop resistance. All sectors of the industry should address this looming problem.

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DISTRIBUTION OF BRIDAL CREEPER (*MYRSIPHYLLUM ASPARAGOIDES*) IN WESTERN AUSTRALIA

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Summary. Bridal creeper (*Myrsiphyllum asparagoides*) is widespread in the south-west of Western Australia. The weed has a disjunct distribution, isolated but severe infestations occur throughout the area, particularly associated with old settlements and town sites. It is likely that bridal creeper in the south-west of Western Australia has yet to reach the full extent of its distribution and impact on native vegetation.

INTRODUCTION

Bridal Creeper, *Myrsiphyllum asparagoides*, is a significant environmental weed in south-western Australia (9). Bridal creeper is of southern African origin and has been grown extensively as a garden plant. The weed is spreading rapidly through bushland of high conservation value on roadsides, farmland and public reserves. In this poster we report on surveys of the distribution of bridal creeper in Western Australia as part of the preparation for the introduction of biological control agents (17) and for the eventual proclamation of bridal creeper as a noxious weed in south-west Western Australia.

METHODS

Surveys were started in 1990 to establish the extent of infestation. Data were compiled from records of roadside populations (first author), records held by the Department of Conservation and Land Management, including records of the Western Australian Herbarium, and from infestation reports of the Agriculture Protection Board (second author).

RESULTS AND DISCUSSION

The plant is widespread and was found at over 90 localities during the roadside survey, spread throughout the middle and lower south west of Western Australia. Plants were found south west of Regans Ford (30°59'S 115°42'E) in the north, Lake Grace (33°06'S 118°28'E) inland and Hopetoun (33°57'S 120°07'E) in the east (Fig. 1).

The Department of Conservation and Land Management Herbarium records show that the eastern extremity of bridal creeper occurrences in Western Australia are Israelite Bay (33°38'S 123°52'E) and Toolinna Cove (32°44'S 125°01'E) on the coast of the Nullarbor Plain (Fig. 1). These locations are in the Nuytsland Nature Reserve. Plants have also been observed at Dongara (29°15'S 114°56'E) (Keighery pers. comm.) which is 210 km north of plants found at Regans Ford. Bridal creeper has been recorded in other nature conservation reserves in the south-west of Western Australia (10), particularly the wheatbelt (Table 1). Bridal creeper has been recorded in 9 of the 43 National Parks in the south-west of Western Australia (Table 2).

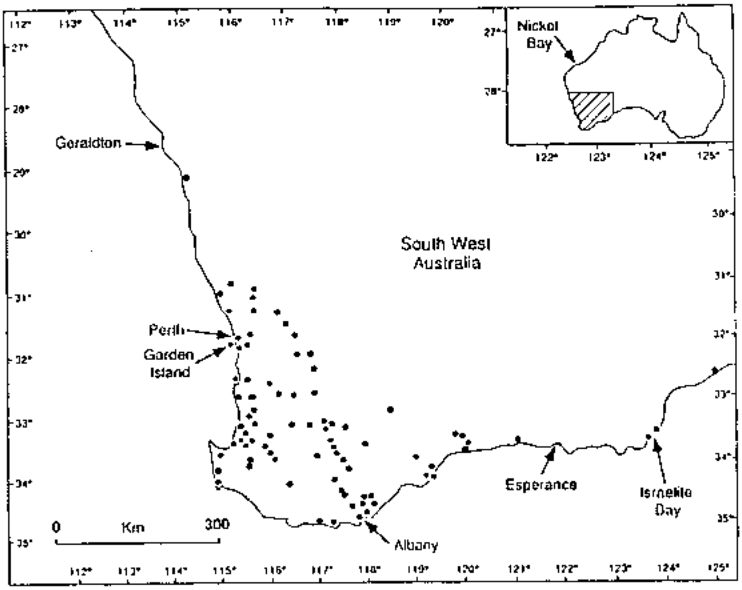

Figure 1. Distribution of *Myrsiphyllum asparagoides* in Western Australia.

Table 1. Known infestations of bridal creeper on CALM nature reserves in south-west Western Australia.

Nature Reserves	Shire	Source
4569/1711	Broomehill	6
9219	Kent	6
10914	Tambellup	6
10930 & 25711	Dumbleyung	6
24599 & 32204	Katanning	6
29860	Lake Grace	6
29182, 6798 & 9718	Pingelly	3
25705	Albany	3
8478	Bridgetown/Greenbushes	3
A29977	Northam	3
Town reserves	Manjimup	3

Table 2. Known infestations of bridal creeper in National Parks in Western Australia.

National Park	Shire	Source
Yanchep	Wanneroo	1
Neerabup	Wanneroo	10
Yalgorup	Waroona	10
Tuart Forest	Capel	10
Leeuwin/ Naturaliste	Busselton & Augusta - Margaret River	10
Stirling Range	Cranbrook	10
Fitzgerald River	Jerramungup - Ravensthorpe	2, 4
Stokes	Esperance	10
Cape Arid	Esperance	2, 10

Additional published records of bridal creeper are known from banksia and tuart woodlands near Perth (8, 11) and the Warren Botanical subdistrict (7). The weed is well established in the Perth metropolitan area at locations including Woodman Point (14), Bold Park (12), Star Swamp, Trigg Dunes and Forrestdale Lake (Pigott, unpublished data), and Kings Park (17).

An 1886 record of bridal creeper from Nichol Bay in the Pilbara (16) (Fig. 1) appears to be anomalous as there has been no further records from the region. The earliest confirmed record is 1956 for plants found on Garden Island off the coast near Perth (15).

Bridal creeper has also been recorded by the Agriculture Protection Board as occurring in 33 south-west shires including drier parts of the southern wheatbelt. Reports from this source are known to be incomplete because of the informal nature of the reporting request (ie. bridal creeper is not a declared plant and does not have to be reported). From our other records bridal creeper is known from an additional 9 shires not including local government areas of metropolitan Perth. In total, bridal creeper is found in more than one third of south-west shires and notably all coastal shires between Perth and Esperance.

Bridal creeper populations are often centred on old settlements and town sites indicating that humans are a major source of initial spread. Invasion into remnant vegetation is mostly attributed to escapes from gardens and garden refuse, and also to seed dispersal by birds and flowing water (13). However, while Western Australian Herbarium records indicate that bridal creeper has long been established at some sites (eg. old Telegraph Station at Israelite Bay), the weed has not spread from these locations. In contrast, populations at other locations (eg. Woodman Point) have spread extensively through undisturbed remnant vegetation in recent times (Keighery, pers. comm.).

Control options being considered for bridal creeper include herbicide treatments (eg. 13), and the introduction of biological control agents (17). The weed is being considered for proclamation as a noxious weed or as a shire pest plant in south-west Western Australia.

ACKNOWLEDGEMENTS

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A NEW APPROACH TO WEED CONTROL ON TASMANIAN ROADS

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ROADSIDE VALUES

Roadsides are often considered an unimportant asset, and in many people's minds the fact that a plant grows by the wayside is enough to define it as a valueless weed. Some people consider any plant which is not cultivated is second rate and any natural species as worthless bush to be controlled at every opportunity. A Local Government Act in Tasmania allows indiscriminate cutting of native trees but requires permission before interfering with exotics! Roadsides are in fact valuable havens, harbouring rare plants, unusual plant communities and fine examples of indigenous species. Roadsides are comparable in total area with some of our National Parks, and contain rare flora and fauna as well as fine examples of our cultural heritage. They are also viewed by multitudes each day, framing almost every countryside view.

ROADSIDE WEEDS

Though many roadside plants are valuable, not all of them are. For a variety of reasons some plants are definitely undesirable. Of the many definitions of a weed three are undesirable as roadside plants.

<u>Natural weeds</u> are the prolific, opportunistic, gratuitous plants which rush in to spoil our hard work just after we have dug and tidied the garden, or, on roadsides, just after we have scraped the verges and dug out the drains. In nature, these plants are designed to colonise bare soil. They are very useful, the first in the plant succession. On roadsides they do not seem to understand that they should not grow, even though our traditional activities make an ideal environment for them! Some natural weeds are exotic; dandelions and gorse are such examples in Tasmania, but of course there are native examples too including blackwood and silver wattle.

<u>Social weeds</u> show little more sensitivity than natural weeds. These are perfectly good, useful species of plants growing in the wrong location. For example, the pine tree *Pinus radiata* is planted as a crop in Tasmania, and as such is a useful tree. When its seedlings escape the plantation and lodge in table drains they are "plants out of place", too large for the roadside we have made; and therefore weeds.

Likewise, exotic pasture grasses are acceptable in grazing paddocks, but quite undesirable in road verges where no stock will keep them in control and they become expensive to mow; more weeds. Even the most attractive of trees become a nuisance if growing directly under power lines, and the tastiest fruit tree is nothing but a weed where its fruit makes a road pavement slippery and dangerous.

<u>Ecological weeds</u> are also a particular menace on roadsides. Rampant exotics with no natural predators to keep them in check, they rampage the verges. Sometimes they march stealthily out onto the carriageway, narrowing the traffic lanes and blocking sight lines. At other times they are less bold and simply swamp the indigenous species refuged in the roadside corridors.

It is not uncommon for roadsides to contain rare plants because of the alienation to farmland or other uses of all the surrounding habitat, and in such locations environmental weeds pose a huge threat: unstoppable, unwanted, but largely uncontrollable for fear of damaging the rare plants.

CHARACTERISTICS OF ROADSIDES

In many ways roadsides are ideal havens for weeds. They are very long, narrow pieces of land, open to attack at almost every location.

Vehicle movement is the express purpose of every road, and yet this very movement in the vulnerable corridor is a primary means of spreading weeds. Some vehicles are devoted to carrying seed, hay, stock and other farm produce. Any escaping material can cause an immediate weed problem. Some vehicles service infrastructure such as pipelines and cables. Tyres can pick up weeds, seeds and diseases in one work site and transport them to many others. Gravel and road-making materials are carted around the countryside, and even the most benign passenger vehicle will regularly suck up material in one place and carry it in its own wind to dump it in another location on the roadside.

Dramatic profiles are an inevitable characteristic of many roadsides, especially in hilly Tasmania. As we lay out our flat ribbons of road we inevitably create cut and fill batters and disturb large quantities of soil. The batters are too steep and smooth for easy or natural revegetation, and remain bare for many years. The wind of passing cars dislodges the soil, which collects in the drain and forms a perfect seed bed; weed bed. As the silt builds up and rampant weeds grow they block the drain, so drains are scraped and the whole cycle starts again. Weeds grow thickest where there is plenty of water and fine soil; in a drain.

Anonymity is both a positive and negative factor. As already mentioned, roadsides contain many treasured plants simply because no-one cared to cultivate them as they did the paddocks. In this way the neglect has been benign. However the neglect of problem plants on roadsides has led to the unchecked spread of many weeds. In my own locality I have watched as the first one of many weed species have moved onto our roadsides. One small gorse bush, one pampas grass, one *Erica lusitanica*. The one has spread to become a few, and before long whole corridors are filled with weeds. Soon the weeds are over the fence and into the farmland. The neglect which allows this kind of weed spread would never be entertained in our domestic gardens.

ROADSIDE WEED CONTROL

The most common practices for weed control on Tasmanian roads are: scraping, where plants and collected silt are simply removed from their location; herbicide spraying, where unwanted plants are left dead in their place; and slashing, where the bulk of above ground material is removed, leaving roots and some shoots still intact in the soil. In part each method is effective, but in large measure each is at best ineffective and at worst counter-productive.

As previously discussed, scraping simply re-opens a new weed bed and may destroy valuable plants along with weeds. The scrapings are rarely carried away but usually windrowed, thus exposing even more soil and potential weed bed.

Herbicide is generally non-selective in its destruction and leads to denudation of the ground and creation of a new weed bed. We have one striking example of this in Tasmania, where almost every table drain is infested with the large pasture grass *Paspalum*. This invasion was caused by repeated indiscriminate sprayings of the drains in spring when most other plants are vigorous but *Paspalum* is dormant. In this way all competition was removed, leaving a seed bed ready for autumn invasion by the *Paspalum*. Herbicide spraying has actually promoted this major weed.

Weed control by slashing is undoubtedly effective in the short term, reducing the biomass. It may also prevent seed spread if carried out at the correct time. However the removal of foliage only encourages the development of latent buds and lignotubers, and trees are encouraged to coppice or form epicormic regrowth and thus the unwanted vegetative material is actually increased rather than decreased.

In our opinion, the millions of dollars spent in Tasmania on roadside weed control of one kind or another is largely misspent (and there are $2 million spent by the power authority in tree cutting alone). Almost all of the work consists of repetitive, indiscriminate programs carried out regardless of needs or results.

Greening Australia and a number of others in the community have begun a process to try to improve roadside vegetation management. Some new approaches have been identified and are being tried in small ways.

NEW APPROACHES TO EFFECTIVE ROADSIDE WEED CONTROL

New techniques can be sorted into different categories. Some of the suggestions are quite inexpensive, but even the more costly and labour intensive ones could be easily financed by simply abandoning the old ineffective practices and relocating the funds.

There are four categories of technique: awareness raising, so that workers have a better understanding of what plants really are roadside weeds, and why; maintenance and construction practices which avoid the creation of weed havens; selective control of weeds, using methods tailored to the specific problems which exist; and joint professional and community-based initiatives for control of roadside weeds.

WEED AWARENESS RAISING

Most people in the general community have a fairly low awareness about weeds. Before being exposed to weed experts most of us would have simply thought a weed was a dandelion or blackberry. In controlling roadside weeds, we have found it is useful to remember that there are no bad plants, not even good ones, only some plants in a helpful situation and others inappropriately placed. Plants come to us with their own special characteristics and we need to use them wisely, not try to change their nature.

In attempting to change the attitudes of some Tasmanian road workers, Greening Australia (Tas) has held numerous discussions, training sessions, field days and plant identification exercises. They have shown many colour slides of different plants and tried to explain their growing habits, benefits and impediments in different roadside locations. With this increased knowledge the workers have begun to appreciate that their real task is to find effective ways to manage each of the roadside plants, not simply to seek ways to destroy them all.

WEED AVOIDANCE

As already noted, many common roadside practices create areas of disturbance and exposed soil. In new road-making a certain amount of ground remodelling is essential; however roads which minimise that reshaping are better aesthetically, ecologically, from a landcare point of view and for weed prevention. They are generally also cheaper in the long run.

Where disturbance is necessary it is also most desirable to encourage rapid revegetation for all of the above reasons. Revegetation is generally most effective when batters are laid back and bare areas topsoiled, roughened, seeded and mulched. Bare roadsides with smooth, steep batters have been common in the past. These encourage erosion, drain silting and weed invasion and subsequent spread. They also look awful.

One very effective procedure in roadside weed control is therefore to avoid soil disturbance where possible, both in construction and maintenance work. Where plants must be removed, be selective and do not carry out blanket denudation. If soil disturbance is unavoidable then reinstate the vegetation immediately.

In Tasmania we have devoted considerable effort to these principles in enlightening road design engineers and in training maintenance and construction workers. We are producing a land calendar to (amongst other things) alert operators to the times of year when weed seeds are most prolific, so they can defer soil disturbing activities. In the field and in training sessions we are helping with identification of native plant communities so these can be kept pristine, and we are encouraging the use of already-disturbed and weedy areas for spoil dumps, vehicle parks etc.

One outstanding example of soil-conscious road making was tried in one Tasmanian forest location neat St Helens. Here, APPM and Forestry Commission jointly planned and constructed a road along a granite ridge-top to minimise soil disturbance. The road location dictated a complete reversal of usual logging operations but was in every way most successful, allowing logging on a very mobile soil which would otherwise have been unharvestable. Minimum soil and vegetation disturbance also meant minimum opportunity for weed invasion.

SELECTIVE WEED CONTROL

Despite all the work on awareness and avoidance, Tasmanian roadsides do have many weeds which need to be treated. The problems range from the rampant pasture grasses *Phalaris* and *Paspalum* blocking drains to large trees growing under power lines and massive infestations of gorse in close proximity to valuable native plant communities and even to rare and threatened species. Each specific weed problem needs to be treated in its own appropriate way.

Greening Australia is working with HEC tree clearing gangs to teach them effective pruning techniques in place of their old hacking method which actually promoted unwanted regrowth.

To out-compete weeds and reduce the biomass and need for mowing, we are assisting with work on native grasses. Though the field is largely new and untried in our State, we have commissioned the preparation of a native grasses handbook and have also assisted both State and Local Government authorities to establish trial plots for kangaroo grass this winter.

Where vigorous weeds and rare indigenous plants grow together very particular care is needed. With specialist advice from the Department of Primary Industries and Fisheries, Greening Australia (Tas) has involved local authority workers in hand removal and cut stump poisoning of gorse plants growing over rare plants of *Spyridium microphyllum* and *Acacia axillaris* on the St Pauls River.

These are just a few examples of the diverse methods being tried as replacements for the old, ineffective, blanket weed control methods which were previously so common on our roadsides.

JOINT ROADSIDE STEWARDSHIP

To raise the public interest and awareness of their potential involvement in roadsides, Greening Australia (Tas) has selected lengths of healthy indigenous roadsides for special attention. On one such roadside a group of "Friends of the Roadside" has been formed. In July they held a joint working bee with the responsible authorities. Volunteers used knapsack sprays and kitchen knives to attack individual problem weeds in a Bradley-style campaign against invading plants. On the same day the professionals mowed the weed-infested drains with a heavy duty tractor-mounted slasher, in a new program replacing the old indiscriminate spraying regime.

Except for the odd mistakes, the outing was very successful and we believe it shows a pattem for the future where both public opinion and volunteer working bees can help the professional road managers to improve their roadside practices and be more selective in weed control. Such days are not only useful work, but they also serve to allow the public and the road workers to better understand each other's points of view. In addition the rather scorned road workers come to feel more highly valued and then become more motivated and creative in their maintenance work.

CONCLUSION

In conclusion, we are able to report that the Tasmanian program of roadside weed control is proving interesting and beginning to show success. As new ideas are taken up by different groups we are seeing their initiative blossoming and even more selective and innovative weed control methods being developed. There is no doubt that in the expensive business of weed control money will be saved, ecological values will be upheld and the community's sense of responsibility and participation will be enhanced, all while pursuing more efficient and effective weed control on roadsides.

ABORIGINAL AND NON-ABORIGINAL RECOGNITION AND AWARENESS OF NOXIOUS PLANTS AND CONTROL MEASURES

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Summary. The purpose of the survey was to compare Aboriginal and non-Aboriginal respondents' recognition of and attitudes towards noxious weeds and their control methods. Three geographical areas, which consisted of diverse country, were selected for the survey. The survey drew upon 210 respondents, 70 from each of these areas in north-western New South Wales. Results of the survey indicated that Aboriginal and non-Aboriginal respondents do recognise noxious weeds and that overall 50 per cent of these weeds are not regarded as a problem. These patterns appear to be in conflict with proposed government noxious weed control management plans and strategies in which chemicals seem to continue to play a major role in the newly advocated integrated control system.

INTRODUCTION

A comparison of Aboriginal and non-Aboriginal recognition of noxious weeds and preferred methods of control was chosen as a survey topic for it was an interest in my field of employment as a Chief Weeds Officer.

Aboriginal and non-Aboriginal landholders are subject to the same policies of noxious plant control. For this reason, the survey intended to compare experience and land ownership as well as related attitudes towards noxious weeds and control measures among Aboriginal and non-Aboriginal respondents.

METHODS

On the basis of my knowledge as a weed officer, the survey was designed around various habitats of noxious plants. The three geographical areas chosen for the survey were Tenterfield, Inverell and Moree Plains Shires. Each shire is geographically different and contains different noxious weed species.

Respondents with rural experience were located through the use of weed officer network and contacts made from a pilot study carried out in 1991. The pilot study was used to test two instruments, a visual aid and a structured interview devised by myself. The visual aid was improved from 26 black and white line drawings of noxious weeds to 26 colour photographs from Agfact pictorial indexes. The aim of the visual aid was to draw upon respondents' past experience, recognition and opinion of noxious weeds in relation to very concrete examples. The questionnaire consisted of three sections. These included respondents' background, noxious weed recognition and attitudes towards noxious weeds. The interview groups included equal numbers of Aboriginal and non-Aboriginal people in each region.

RESULTS

On average, participants in the survey indicated that they had been living/working on the land "all their lives". The correlation between age and experience accounted for higher proportions of non-Aboriginal respondents with experience on the land.

The range of noxious weeds recognised shows that respondents identify the following species most frequently, Prickly pear (*Opuntia stricta*), Blackberry (*Rubus fruticosus*), Water hyacinth (*Eichhornia crassipes*), Pampas grass (*Cortaderia selloana*) (Fig. 1). Noxious weeds which are not recognised vary with area, although some plant species (e.g., Green cestrum (*Cestrum parqui*), St John's wort (*Hypericum perforatum*) and Nodding thistle (*Cardu nutano*)) are not commonly registered at all.

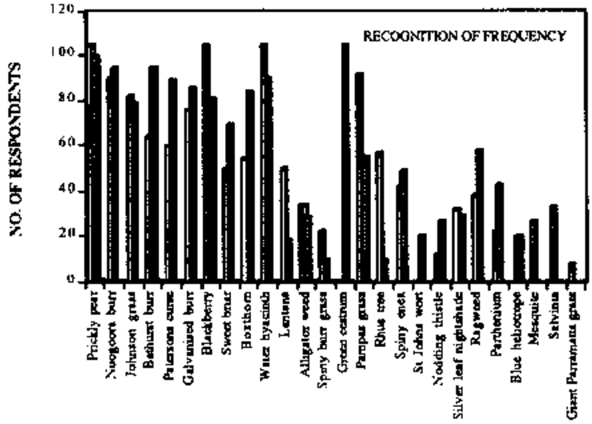

Figure 1. Recognition of noxious weeds Aboriginal versus non-Aboriginal respondents

In order to investigate why some noxious weeds were recognised more than others, weeds were classified into three categories. These categories included aquatic, garden escapes and common weeds.

For the purpose of the survey "common weeds" is a category devised for noxious plants which are common in all three areas. Focussing on these categories enables the survey to explain and compare noxious plant recognition. The only difference in weed recognition across these categories occurred for "aquatic weeds" where the level of recognition among Aboriginal respondents is significantly higher than among non-Aboriginal. Respondents were also asked to indicate whether they would classify any of the noxious plants as either fodder or food. Johnson grass (*Sorghum halepense*) was the only noxious weed recognised in the survey for its fodder qualities. Twenty per cent of the total number of respondents regarded Johnson grass as a useful fodder for stock, particularly in the western and central areas where its drought tolerant qualities act as an aid for stock survival. In the eastern area Aboriginal respondents less frequently recognised Johnson grass because a higher rainfall pattern reduced their dependence on the plant grass as fodder. Responses from all three areas however show that Johnson grass is thought to have positive and beneficial qualities.

One quarter of the total number of respondents recognised the food value of a fifth of the noxious plants in the survey. Aboriginal respondents more frequently recognised potential food plants than non-Aboriginal respondents. Blackberry and Water hyacinth proved to be particularly popular food plants among Aboriginal respondents.

Problems caused by noxious plants. Non-Aboriginal respondents prioritised problems caused by noxious weeds as:

1.	Stock	46%
2.	Crops	31%
3.	Man	14%
4.	Environment	9%

Aboriginal respondents prioritised the problems as:

1.	Stock	40%
2.	Crops	24%
3.	Environment	10%
4.	Man	26%

Thus Aboriginal and non-Aboriginal respondents appeared to hold similar views. Aboriginal respondents however, particularly females, displayed a greater concern for damage to the environment than non-Aboriginal respondents. Interviews indicated that the latter appeared to be more concerned about how their income would be affected by noxious weeds than about how they might harm the environment.

Noxious plants not seen as a problem. Noxious weeds regarded as non-problematic by Aboriginal respondents included Water hyacinth, Galvanised burr (*Sclerolaena birchii*), Sweet briar (*Rose rubiginosa*), Salvinia (*Salvinia molesta*), Patersons curse (*Echium* spp.), Silver leaf nightshade (*Solanum elaeagnifolium*) and Alligator weed (*Alternanthera philoxeroides*). Noxious plants regarded as non-problematic by both Aboriginal and non-Aboriginal respondents include Prickly pear, Johnson grass, Blackberry, Pampas grass and Rhus tree (*Toxicodendron succedaneum*). In total, 12 out of 26 noxious weeds in the survey, almost 50 per cent, were considered non-problematic. Thus an elderly Aboriginal woman explained why she does not regard the noxious plant Galvanised burr as problematic.

Too much taken from the land caused this plant to fight back.

Too often the weed is blamed rather than man's interference with the land.

METHODS OF WEED CONTROL

Methods of weed control used by Aboriginal and non-Aboriginal respondents were similar in pattern though differed in emphasis (Fig. 2). Chemicals have been used by 54 per cent of non-Aboriginal and 21 per cent of Aboriginal respondents. A definite preference was indicated by 84 per cent of all respondents for less use of chemicals (Fig. 3). More support was shown for alternative noxious weed control methods such as grazing and burning.

Respondents' preference for less or no chemical use is in contrast to governments' future control plans and strategies. Total Catchment Management, advocated in the National Weed Strategy (1) and the NSW Weeds Act, for example, combine an Integrated Pest Management program in which chemical application remains the dominant method of control. Alternative methods such as burning and grazing may not be as effective or efficient as chemical control. This would mean that Aboriginal and non-Aboriginal respondents could be liable under the Noxious Weed Act of 1993 (2). The Act states that failure to effectively control noxious weeds may result in a maximum penalty of $10,000. Local authorities may also enter the land and chemically control the noxious weeds, and charge the landholder accordingly. Failure to pay the fine or to reimburse authorities for control measures may result in the sale of land to recover these costs.

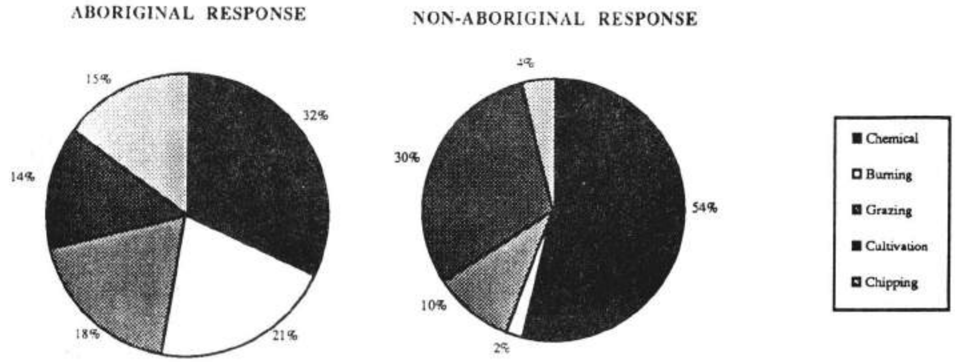

Figure 2. Methods of weed control used by Aboriginal and non-Aboriginal

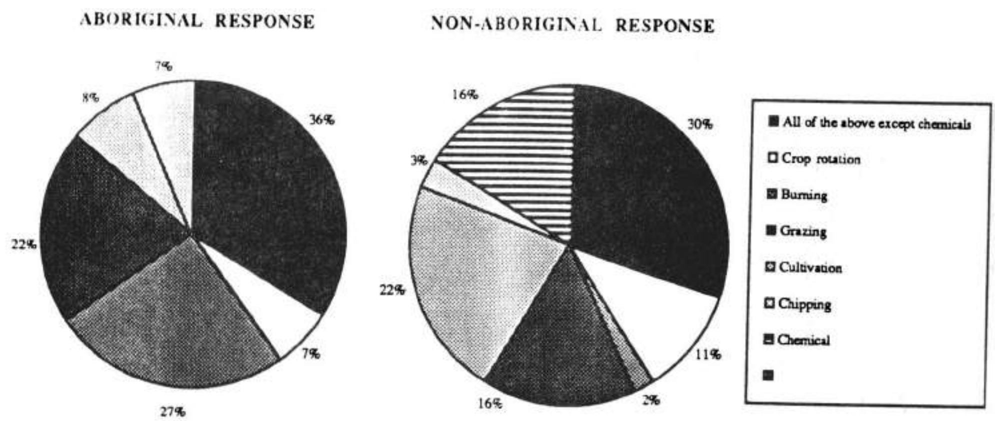

Figure 3. Methods of weed control preferred to be used more in the future by Aboriginal and non-Aboriginal

Given that Aboriginal people have used chemicals much less frequently than non-Aboriginal respondents in the survey, given that Aboriginal and non-Aboriginal respondents prefer other methods of control, and given that the National Weeds Strategy is proposing special legislation to address specifically Aboriginal people's approach to weed control, the new legislation at state and federal levels may in fact become a tool to constrain Aboriginal land ownership.

ACKNOWLEDGEMENTS

I wish to express my gratitude for the relentless and enthusiastic guidance of my supervisor Associate Professor Ann-Katrin Eckermann, Head, Department of Aboriginal and Multicultural Studies, University of New England.

I also wish to thank Glenda Kupczyk-Romanczuk for her help with English expression.

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WEED CONTROL AND THE CO-OPERATIVE RESEARCH CENTRE FOR TROPICAL PEST MANAGEMENT

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Summary. The Co-operative Research Centre for Tropical Pest Management (CTPM) in Brisbane is formed from the Entomology Divisions or Departments of the University of Queensland, CSIRO, Queensland Department of Primary Industries and Queensland Department of Lands. CTPM staff are involved in research into all aspects of improved management of tropical pests, with a significant section involved in biological control of weeds. Australia is a world leader in this field, and over 50% of Australian weed biocontrol occurs in 2 of the CTPM participating institutions. The CTPM offers new educational opportunities for weed scientists in the region, with a new intensive 2-week course on Biocontrol of Tropical Weeds, and course-work Diploma and Masters as well as research degrees at the University of Queensland, all taught or supervised by experienced weed biocontrol scientists.

INTRODUCTION

The Co-operative Research Centre for Tropical Pest Management (CTPM) was formed in Brisbane in 1991, one of the first of 50 Co-operative Research Centres funded by the Australian Government for a 5-year period, in a move to increase the links between scientific research, industry and education. The CTPM was formed from 4 participating institutions, CSIRO Division of Entomology at Long Pocket, Queensland Department of Primary Industries Entomology Branch (as it was then), Queensland Department of Lands Alan Fletcher Research Station, and the University of Queensland Department of Entomology. CTPM headquarters are at the University of Queensland and Dr Geoff Norton, well-known for his work at Imperial College on the economics of pest management, is Director.

RESEARCH PROGRAMS

The main thrust of research at the CTPM will be towards improved management of tropical insect pests, but there is also a significant section involved in biological control of weeds. Australia is a world leader in this field, and over 50% of Australian weed biocontrol occurs in Brisbane, at CSIRO Longpocket laboratories and at the Alan Fletcher Research Station, both participating institutions in the CTPM. The existing programs of these institutions will continue, but the CTPM will bring an increased thrust towards basic understanding of the mechanisms governing biological control of weeds.

One core CTPM program aims to improve the accuracy of predicting the effects of potential biological control agents on weeds. The behaviour of the insects involved and the responses of the weeds to their attacks are important factors in determining the level of injury, and therefore of control, inflicted by a given insect population. The core activity of this research will be the development of a generic computer model of plant growth, able to simulate responses of plants, ranging from grasses to trees, to insect attack. Basic data on the growth of the plants and their responses to insect damage are being collected for several plants including the important weeds parthenium *Parthenium hysterophorus* and water hyacinth *Eichhornia crassipes*. This data will provide the basis for developing and testing the model. The generic plant model will eventually be interfaced with the generic insect population model being developed by the Centre, and the package then incorporated into decision-support and computer-aided learning software for improved weed management. Dr Peter Room of CSIRO and Dr Jim Hanan, a CTPM Post-doctoral Fellow, are responsible for this program.

Another program investigates the basis of host specificity and host selection by weed biocontrol agents, and the differences in host selection behaviour in cages and in the field.
A PhD student Ms Seemi Khan is investigating host selection in the moth *Epiblema strenuana*, released as a biocontrol agent for parthenium weed. In its native home in north America as well as in Australia, the moth never attacks sunflower, which is closely related to parthenium. Yet both Chinese and Indian biocontrol scientists report significant attack on sunflower and other related plants in cage tests. Seed of sunflower cultivars from India and China have been obtained and field and cage tests are in progress. These will be followed by experiments to determine the chemical basis for host selection in this moth. This work ties in with and will be strengthened by other research within the Centre on the chemical basis of host selection in plant-feeding insects.

A third program is studying eutrophication of water and its effect on biological control of water hyacinth. This is a new Centre initiative, and is the first step towards improving our understanding of biocontrol of serious waterweeds such as salvinia *Salvinia molesta*, water hyacinth *Eichhornia crassipes* and water lettuce *Pistia stratiotes* in eutrophic waters. This program also links with the plant growth model, which will be used to help analyse data from eutrophication experiments. Mr Shaun Witherton (CTPM) will be conducting the experiments with CSIRO scientists Mr Tony Wright and Dr Tim Heard.

EDUCATION

Together with these new research programs, there is an increased emphasis on education. The first intensive 2-week course on Biocontrol of Tropical Weeds was held in May this year, with 10 participants from Uganda, Vietnam, Thailand, Fiji, the Solomon Islands, Indonesia, the Philippines, and Australia. Pressure to reduce use of chemical herbicides and move towards "sustainable" land use is leading to increased interest in biological weed control in many countries, but there are few experienced biocontrol scientists in the region except in Australia. This course provides expert and "hands-on" training for weed scientists and agricultural entomologists, equipping them to run or supervise a weed biocontrol program in their own country. It is also extremely valuable for senior agricultural scientists who may have to make the decisions regarding importation and release of insects as biocontrol agents against weeds, as it equips them with the background knowledge and experience necessary to evaluate weed biocontrol applications. The course will be run again in March 1994, and in future years according to demand.

The education program of the Centre incorporates aspects of all the Centre's research programs. The Centre is enhancing and adding to education in Tropical Pest Management within the University of Queensland through undergraduate lectures, postgraduate research and supervision, and development of innovative teaching methods (eg Computer Assisted Learning, CAL) for use by a range of clients from students through to industry consultants. Through the Centre, there is an increased contribution of non-University research staff to undergraduate courses, which means Agriculture students, for example, learn about weed control programs at the CSIRO and the Alan Fletcher Research Station, and can undertake final-year projects at these laboratories under the supervision of CSIRO and AFRS scientists. Vacation scholarships are offered for projects in any of the CTPM's centres, with students able to work on diverse projects including aspects of weed control. Post-graduate students can enrol for Diploma, Masters and PhD degrees at the University of Queensland, based at these participating organisations, and under the supervision of experienced weed scientists. Diplomas and Masters degrees in Tropical Pest Management can include courses in weed control and management, as well as a wide range of other options such as the use of plant growth models, expert systems, or economics of pest and weed management.

PREDICTIVE AND EXPERT SYSTEMS AND COMPUTER ASSISTED LEARNING

CLIMEX, the PC/DOS-based computer package for predicting the effects of climate on plant and animal distributions, has been refined to be more user-friendly. It can be used to predict the potential Australian distribution of new weeds, or the effect climatic change might have on existing weeds. CLIMEX for Windows will be available in 1994, and a Training Course for users of CLIMEX will be run at the University of Queensland in October this year. Short training courses for CLIMEX users can be arranged as required. An educational version of CLIMEX which addresses geographical and ecological issues, is also being developed. Dr Bob Sutherst, Gunter Maywald and Bryce Skarratt are the scientists working on CLIMEX development.

Other CAL initiatives are DIAGNOSIS, a computer program intended to teach crop consultants and undergraduates the process of diagnosis and management of crop-production problems, for example unexplained plant deaths in a crop which could be due to several possible causes. Also for university teaching, a prototype key which uses graphics extensively has been developed for identification of insects to order level. A prototype Expert System on pest-risk analysis has been developed for AQIS; this determines the risk of establishment, reproduction, and spread of a pest organism, combines the factors to give the overall risk associated with the organism, and refers to management options for this risk. This is now being further developed into a functional system. Robert Merlicek and Bruce Blackshaw are the scientists responsible for these projects, and they could readily adapt these CAL and Expert Systems for use with weeds if the demand is there.

WORKSHOPS

An important part of the CTPM approach to pest management is the involvement of the user community from the outset ie at the problem-definition stage. This is achieved partly through close links with industry bodies, through the CTPM Consultative Group of industry representatives, and through the CTPM newsletter Tropical Pest News and other informal direct links. Problem-Definition Workshops are another major way of bringing industry, the users of research, into the process. These Workshops bring scientists, economists, funding body representatives, crop consultants and farmers/graziers, together into a 2 or 3-day workshop to consider a particular research problem. The CTPM has held several such Workshops already and more are scheduled. The CTPM offers support in facilitating the Workshop and producing the report, which allows the scientists to concentrate on reviewing the problem, brainstorming all possible options, and finishing with solid and well-thought-out recommendations.

CONCLUSION

Through its participating organisations, the CTPM is already extensively involved in weed biocontrol in Australia as well as the Asian-Pacific region. It is our hope that the CTPM will result in greater co-ordination and depth to our research as well as a better use of resources. The CTPM offers unique opportunities for university-level education in weed control in the tropics, and we hope these will be increasingly taken up by scientists from the Asian-Pacific region. In particular, the considerable expertise within the CTPM in developing computer models and expert systems for pest management is an enormously valuable resource, and we look forward to developing these systems for use by weed scientists.

ACKNOWLEDGEMENTS

I would like to thank my fellow staff at the Co-operative Research Centre for Tropical Pest Management for their help in summarising their projects, and for their assistance in correcting my earlier drafts.

WEED RESEARCH IN INDIA, AND FUTURE THOUGHTS

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THE DEVELOPMENT OF WEED SCIENCE IN INDIA

Early attempts at chemical weed control in India included the control of water hyacinth by application of steam and formalin (4) and the use of sodium arsenite in 1937 for controlling *Carthamus oxyacantha* in Punjab. In 1952 the Weed Control Section started in the Division of Agronomy at the Indian Agricultural Research Institute, and in the same year the Indian Council of Agricultural Research (ICAR) launched the first Coordinated Weed Control Scheme in eleven states to monitor the weed flora of the country and research the feasibility and effectiveness of 2,4-D, MCPA and MCPB. The overall impact of this scheme on Indian agriculture, however, remained marginal. At that time work was also being carried out by using 2,4-D to control weeds in sugarcane in Maharashtra (2, 3) and in wheat at Agra (7), whilst in Assam research started to control weeds in tea by herbicides.

With the creation of the State Agricultural Universities from the early 1960s weed science research became more general, also occurring at the ICAR Institutes, Agricultural Colleges and Central Universities.

The Indian Society of Weed Science was established in 1968, and the first number of the Indian Journal of Weed Science was published in 1969. The Society now has close links with other international weed science societies.

Real importance was given to weed science research in India from 1978-79 onwards through the USDA-PL-480-ICAR All India Coordinated Research Project. This took place in 22 locations covering all agro-climate regions of the country, in three phases. The first phase started in 1978-79 at six centres in Punjab, Karnataka, West Bengal, Madhya Pradesh, Uttar Pradesh and Himachal Pradesh, and included both fundamental and applied aspects of weed management in different field and plantation crops. The second phase started in 1982-83 when the project was extended to centres in Assam, Gujarat, Faizabad, Bangalore, Jhansi and Tamil Nadu. In the third phase from 1985-86, nine more centres were included in Bihar, Haryana, West Bengal, Uttar Pradesh, Kerala, Orissa, Andhra Pradesh and Meghalaya. After four years of funding from USDA-PL-480-ICAR, the centres are continuing weed science research work directly under the ICAR.

The latest effort to strengthen weed research in India has been the establishment of the National Research Centre for Weed Science (NRCWS) by the ICAR in 1989 at Jabalpur, as a nodal Institute in Weed Science to provide leadership in basic and applied multi-disciplinary research. The Institute is conducting research into weed management in cropping systems, the biology and agro-ecology of weeds, vegetation management in non-crop areas and aquatic environments, residue chemistry and weed physiology, and social science and the transfer of technology.

RESULTS OF INDIAN WEED SCIENCE RESEARCH

In the beginning, screening and selection of herbicides for particular crops seem to have been the major concern. Substantial work was done to identify weed management practices for wheat, rice, sugarcane, oilseeds, pulses, maize, sorghum, cotton and plantation crops between 1963 and 1978 (Table 1).

Table 1. Herbicides recommended for different Indian crops

Crops	Herbicides
Cereals, Oilseeds, Pulses	
Rice	2,4-D, propanil, butachlor, thiobencarb, oxadiazon, pendimethalin
Wheat	2,4-D, isoproturon, methabenzthiazuron, metoxuron
Maize	simazine, atrazine
Sorghum	simazine, atrazine
Rapeseed and Mustard	fluchloralin, isoproturon, pendimethalin
Sesame	alachlor, fluchloralin, pendimethalin, metolachlor
Groundnut	fluchloralin, pendimethalin, metolachlor
Pulses	fluchloralin, alachlor, pendimethalin
Fibre, sugar crops and plantation crops	
Cotton	diuron, alachlor
Jute	fluchloralin
Sugarcane	2,4-D, atrazine, simazine
Tea	glyphosate, paraquat
Coffee	paraquat + diuron, 2,2-DPA + 2,4-D

CURRENT WEED SCIENCE RESEARCH IN INDIA

Weed survey and weed biology. A weed survey of different regions of the entire country will result in the preparation of weed maps. Studies have started on the biology of problematic weeds of different regions and their control

Integrated weed management in specific crops and cropping systems. The integrated approach of weed management has revealed the scope of using herbicides at reduced rates by combining them with intercultural operations, agronomic manipulation, and with growing inter-crops.

Allelopathy studies. Allelopathy studies have shown the interactions listed in Table 2.

Translocation of herbicides. The translocation pattern of foliar applied radio-labelled 2,4-D is being studied in *Oxalis latifolia*, *Parthenium hysterophorus* and *Solanum elaeagnifolium*.

Herbicide residue estimation and management. Herbicide residue estimation work is going on at Coimbatore, New Delhi and Kalyani, and herbicide residue management studies have started in several Agricultural Universities.

Table 2. Weeds affecting crops allelopathically in India

Weeds	Affected plants
Phalaris minor (dry straw), *Chenopodium album*, *Silene conoides*	Wheat
Root extracts of *Trianthema portulacastrum*	Sorghum, finger millet, maize, pearl millet, red gram, sesame and cotton
Whole plant extracts of *Portulaca oleracea*	Okra, jowar, cluster bean, green gram and ragi
Extracts of *Cassia sericea*	*Parthenium hysterophorus*

Standardisation of bioassay technique. Solution in soil cultures in laboratory conditions and soil assay in pots in bioassay experiments have been going on with several herbicides, and GR-50 (herbicide concentration to inhibit plant growth by 50%) have been calculated.

Aquatic weed control. Examples of recent successes with the classical approach of biological weed control in India are the use of the weevils *Neochetina bruchi* and *N. eichhorniae* to control water hyacinth, the use of *Cyrtobagous salvinae* to control salvinia, and the use of grass carp (*Ctenopharyngodon idella*) to control submerged aquatic weeds.

Designing and developing weed control tools and implements. At IIT Kharagpur a low cost herbicide applicator with weed attachment (ITTWAM-82) has been developed. The different weed tools that can be attached to this machine include flat blades, flat blades with serrated edges, fine line blades and double blades of improved Aspee make and Philippines design. A power operated aquatic weeder for ponds, canals and larger aquatic bodies has been designed, developed and fabricated for cutting, clearing, and disposing of free floating and submerged aquatic weeds.

FUTURE THOUGHTS ON WEED RESEARCH IN INDIA

Emerging problems in weed management. The repeated use of some herbicides year after year in the same area leads to a shift in weed flora and the appearance of resistant weeds which were hitherto of relatively minor importance (Table 3).

New weed species have come up in different parts of India, and are posing great problems (Table 4).

Herbicides which persist much longer than the desired periods pose several potential environmental problems. Agriculturally they may cause injury to succeeding crop production (particularly in multiple cropping systems), and possibly cause adverse effects on soil microflora and fauna. Residue problems are not only agricultural in scope. Within the last decade the public has become increasingly aware of the potential danger from pesticide residues in the environment. The accumulation of residues in grain, vegetables, fruits and other plant parts, soil and water sources present potential health problems.

Table 3. Shifts in weed flora in India

Crop	Original weed flora	New weed flora
Wheat (first phase)	*Chenopodium* spp., *Spergula arvensis*, *Anagallis arvensis*	*Phalaris minor*, *Avena fatua*, *Lolium temulentum*
Wheat (second phase)	*Phalaris minor*, *Avena fatua*	*Lathyrus aphaca*, *Convolvulus arvensis*, *Medicago* sp., *Cirsium arvense*
Rice (transplanted)	*Echinochloa* sp.	*Cyperus iria*, *Fimbistylis miliacea*, *Sphenoclea zeylanica*
Sugarcane	Broadleaved weeds	Grassy weeds

Table 4. New weed species becoming apparent in India

Region/Crop	New weeds
Waste lands all over India	*Parthenium hysterophorus*
Up hills and N.E. hills region	*Oxalis corniculata*
Rabi crop fields of North Bengal	*Polygonum* spp.
Tamil Nadu (Periyar and Coimbatore district)	*Solanum elaeagnifolium*
Roadsides, waste land, terai hills	*Lantana camara* *Ageratum conyzoides* *Eupatorium* sp. *Parthenium hysterophorus*
Tea gardens	*Imperata* sp. *Mikania* sp.
Tobacco, brinjal	*Orobanche* sp.
Sugarcane	*Striga* sp.
Fencing shrubs, roadside trees, niger crops in Orissa	*Cuscuta* sp.
Water bodies	*Eichhornia crassipes*

<u>Approaches to integrated weed management with stress on non-chemical methods of weed control</u>. Investigations carried out in India over the last two decades have helped identify herbicides for a wide range of crops under different agro-ecosystems to supplement traditional practices of hand weeding and economise on production costs. Considering the diversity of weed problems, no single method of control can reach the desired level of efficiency under all situations, though the effectiveness of herbicides is more pronounced under assured irrigation. This calls for a holistic approach to produce Integrated Weed Management (IWM) packages for cropping systems as a whole. Major components of IWM systems have been identified as non-chemical methods with low cost input, including stale seed beds, minimal cultivation, nitrogen

management, higher crop stand by slightly increasing seed rate and close spacing, intercropping, use of competitive crop cultivars, and supplemental use of herbicides at as low rates as possible (5).

To avoid the possible hazards of chemical weed control, emphasis is being given to biological methods to combat weed problems.

Basic research. Basic research on weed biology and microbiology and the selectivity, absorption, translocation and degradation of herbicides have been going on in one or two centres. These studies need to be intensified.

Utilisation of weeds for useful purposes. Large scale programs for the utilisation of water hyacinth for compost, animal feed, production of paper, hormone and leaf protein, fish food, biogas and water pollution control should be initiated. Many common weeds are used for vegetables and medicinal purposes, whilst other uses of certain weeds include animal fodder, fibres, oil, dyes and tannins.

Problem weeds and their control. Knowledge of problematic and perennial weeds including *Lantana camara, Eupatorium* sp., *Imperata cylindrica, Cyperus rotundus, Saccharum spontaneum, Ischaemum pilosum, Striga* sp. and *Parthenium hysterophorus* which cause serious damage to crops and farm lands is not sufficient to enable the development of adequate control methods, and the biology and ecology of these weeds should be studied in greater detail. Research should be further concentrated on the control of these weeds.

Development and application of biotechnology in weed management. Four areas within the field of integrated weed management offer attractive opportunities for the application of biotechnology. These are the development and use of bioherbicides, the discovery and use of naturally occurring herbicides, genetic manipulation of crop tolerance to herbicides, and use of genetically engineered micro-organisms for the biodegradation of herbicides in soil and water and as herbicide safeners for increasing the selectivity of herbicides. Research in these fields should be initiated (6).

Weed science education. Weed science is currently a component of agronomy in many universities, but the education program is quite weak. The number of students specialising in weed management at post graduate level is very limited. Similarly the number of full time scientists in weed science research is extremely limited.

At present a core course on weed control of 2-3 credits is offered out of 20-25 credits allocated to agronomy at undergraduate classes in some universities. At postgraduate level the situation is slightly better, as one or two separate courses with 3-5 credits are offered. Looking into the importance of weed science and its relevance to crop production it is necessary that students should specialise in weed science as a distinct sub-discipline of agronomy, as is done with crop husbandry and soil and water management (8). Modern weed science is a multi-disciplinary subject encompassing agronomy, botany, soil science, plant physiology, biochemistry, organic chemistry, residue chemistry, toxicology and ecology, and needs to be developed into a separate discipline.

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PEST PLANT RESEARCH USING A WHOLE SYSTEMS APPROACH FOR SUSTAINABLE LAND USE IN QUEENSLAND

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Summary. Key ecological and economic relationships between current methods of pest plant research and a whole systems approach are examined, and the need identified for assessing, planning and applying research outcomes to maximise their effectiveness for achieving sustainable land management in Queensland. Ecosystem understandings are described, linked and qualified in terms of strengths and limitations of contemporary research in weed control. This evaluation identifies why pest plant research needs to be placed appropriately in whole property, catchment or regional systems frameworks to ensure its relevance in sustainable land management. Only when pest plant research is based on a whole systems approach can the resources involved be optimised and research achieve relevant strategic directions and outcomes.

INTRODUCTION

Weed control technology has progressed significantly in the last 30 years. We now have the technology to kill target plants, but not necessarily that to solve the management problems caused by such weeds. Weed science is at the crossroads and is entering a critical period in its development. Decisions made in the next few years will determine if this discipline remains orientated towards weed control technology or develops into a broadly based, scientific discipline (1).

Pest plants in modified and natural ecosystems are often symptoms of maladaptive land use across many scales of impact. It follows that pest plant research conducted in isolation of those whole property or whole catchment management requirements essential for land sustainability, may be shown to be irrelevant. Research priorities need to be placed in a wider framework that allows the impact of economic, environmental and social factors influencing whole property management to be considered in terms of sustainable land use.

If we want to bring about significant improvements in the way we deal with weed control to comply with sustainable land use needs, regulatory requirements, public perceptions and economic limitations, we have to leave monodimensional approaches and develop and implement multidimensional alternatives. Such alternatives should be based on biological and ecological principles within holistic, relational frameworks (2). This paper examines the role of a whole systems approach to pest plant research and its use in ensuring research outcomes are relevant for sustainable land use.

A systems approach emphasises key relationships that help understand and build a 'big picture' of processes involved in a pest plant problem. In systems analysis, such complex problems are viewed as sub-systems of interlocking cause and effect pathways (2).

WHAT IS A WHOLE SYSTEMS APPROACH?

A system can be any scale - a leaf could be a system if the investigation is looking at the effects of environment on fungal populations on the leaf surface; at the other extreme, the earth may be a system if we are considering global climatic change.

In hierarchy theory relevant to systems research, three levels of importance are usually recognised: the level of observation, the level below which influences or explains what happens at the level of observation, and the level above - which is influenced by the changes that occur at the level of observation.

Systems scientists look for general principles that can apply across both natural and social sciences. They support the position that reductionist methods cannot produce a comprehensive understanding of organised, complex systems (3). Systems thinking usually requires the researcher to identify the broad outlines of complex situations, to tolerate high levels of ambiguity, to resist giving undue credibility to entrenched positions, and to be prepared to be intellectually bold.

Understanding the relationships between the elements and their interactions is the key to solving problems for a defined system. Associated methods involve relational frameworks, co-operative research, component investigations, integration and application to management.

ACCOMMODATING LEVELS OF SCALE IN PEST PLANT RESEARCH

Scale in systems investigations needs to be identified in space, time, and as information flow through organisation levels and in terms of emergent relationships.

Key speakers at the 1st International Weed Control Congress (1992) recognised the need for integrated systems management for effective weed control, ecosystem level studies as a framework for weed research, and multi-disciplinary research that places weed life systems investigation in an ecosystem context (4). A number of challenges are involved in pursuing research that seeks to satisfy these requirements, and these relate to limitations in ecological science.

There is no 'unified field theory' of ecology. Understanding of information flow between different levels of scale and through different time phases is limited. Populations need to be treated as second order, *quasi* sub-systems of ecosystems. The identification and judicious use of emergent properties, however, can assist in linking findings at different levels of scale (5). For these reasons it is useful to establish a framework that allows linkage between those major levels of scale that are relevant to specific research projects. Hynes (5) employed a multi-level framework for ecological analyses that extended across major levels of scale.

Recognition of other key factors that may influence the outcome of a research project at other major levels of scale can assist in minimising the risk of overall project failure or irrelevance even though the researcher may have achieved successful outcomes at the level of the investigation.

For research management purposes three major levels of scale are recognised: Level 1 - the **life system** of the subject species including population biology and ecology, autecological and environmental considerations; Level 2 - the **ecosystem/s** within which the subject species persists; and Level 3 - the **land system** within which the respective ecosystems form part of the landscape. Fig. 1 shows how this can provide an operational framework for handling levels of scale in pest plant management research.

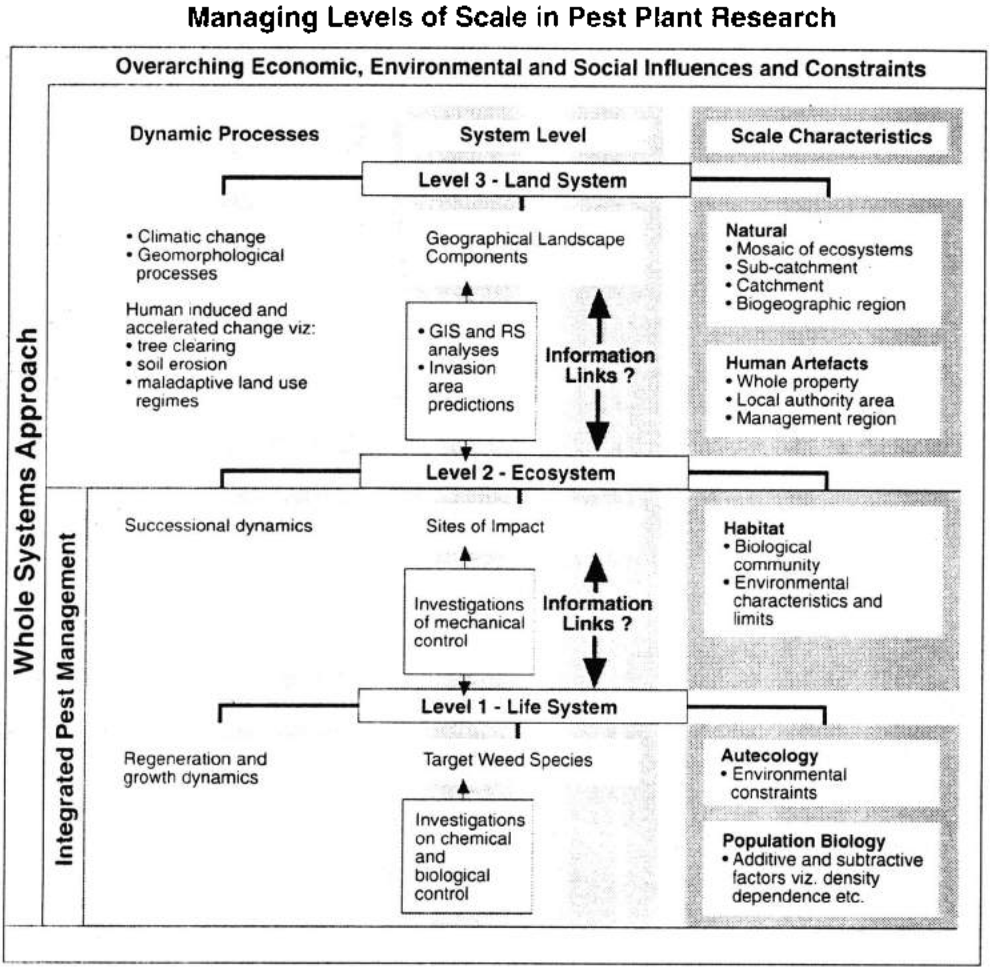

Figure 1. An operational framework for accommodating levels of organisational and physical scale in pest plant research. Systems modelling using computer protocols can be conducted at any level and used for linking information outcomes between levels.

How can we optimise an understanding of ecological and economic principles to allow us to achieve research that minimises plant pest impact within a whole systems framework?

ECOSYSTEMS, PEST CONTROL RESEARCH AND LAND SUSTAINABILITY

Where a natural resource is under-utilised by native species or production alternatives, the door is opened to exotic weed invasions. This is particularly so where large-scale, unpredictable disturbance following long periods of ecosystem stress, eg. drought, can set conditions that release resources that can be exploited by pest plants (Fig. 2).

Renewable resources are those parts of these natural ecosystems that are turning over at rates approximately comparable with rates of use, removal or harvest. Parts harvested should remain well below the maximum potential production of the ecosystem. Overall, the inputs - nutrients entering the ecosystem in rain, from decomposing organic matter or soils - should be about equal to the nutrients in the parts removed. Where lands are used for agriculture, management constraints become complex if we seek to mimic natural processes (6). A systems approach to pest plant research here can assist in accommodating this complexity. The cost to other values, e.g. nature conservation, water quality, also needs to be considered.

Economically, the most efficient investment in control is intervention at the pre-invasion stage and, to a lesser degree, early in the invasion of a site. Expenditure for control during the exponential phase of invasion is usually a poor investment. On the other hand, once niche saturation by a pest has been approached in an area, the introduction of effective biocontrol agents can assist in lowering the vigour of the pest plant under investigation (7).

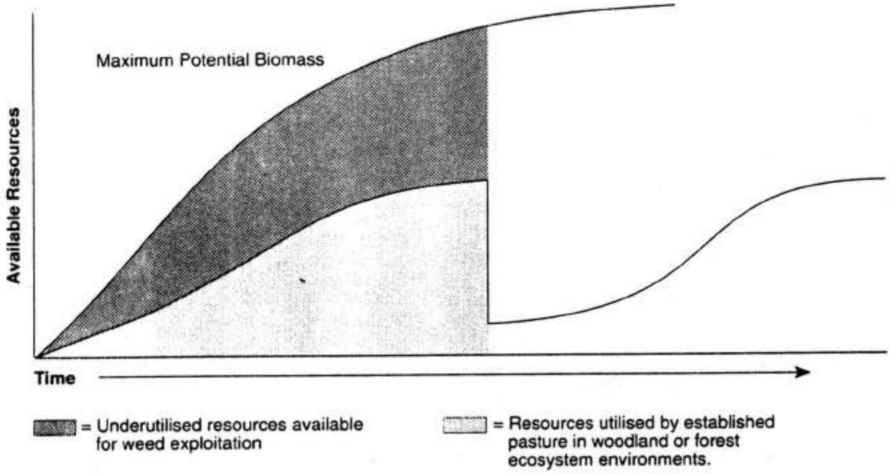

Figure 2. Utilisation of available resources in forest or woodland ecosystems.

Sustainable resource use and efficient economic investment

An understanding of the nature of relationships between natural resources and an open market economy (8) highlights the incompleteness of contemporary economic systems regarding achieving total resource accounting. A wider view of resources, not only recognises use value, but acknowledges that many renewable resources maintain ecosystem integrity, provide ecological services by accommodating wastes, and significantly contribute to environmental amenity, aesthetic and cultural values.

Pest plants are symptoms of maladaptive land management and inadequate resource accounting, and only by substantially strengthening land sustainability management and resource accounting practices can their impact be reduced. Proper resource pricing needs to be part of this process (9). It is critical that this proper recognition of the wider economic dimensions outlined above is considered in contemporary pest plant research. They can also accommodate and highlight the high returns that can be gained from investment in biocontrol research.

CASE STUDIES WHERE A WHOLE SYSTEMS APPROACH IS NEEDED

Examples highlighting the need for wider research frameworks

Case 1. A leaf eating, biological control insect is processed through all stages of research to Australian Quarantine Inspection Service (AQIS) approval and mass rearing for release. It was one of many phytophagous insects living on the target species in the country of origin. When released, the insect is effective in reducing foliage. However, the pest plant is shown to respond vigorously to grazing and ultimately persists as an even more aggressive weed. In this case a deeper understanding of the autecology, biology and vulnerable life stages of the weed could have led to re-ordered priorities with a focus, for instance, on fruit galling insects for biocontrol.

Case 2. A recent, carefully executed herbicide trial in New Zealand focused on the control of exotic conifers and native woody species at and below the tree-line. This investigation was located in an area where treeless landscapes were apparently more attractive to the tourist industry. There is little doubt that at a significant cost these herbicides would be temporarily effective. The control program here, however, is basically flying in the face of nature. Tree-lines, apart from shorelines, are perhaps the most persistent naturally maintained ecotones on earth. Woody plants will continue to recolonise this area. The control program in place is a high price to pay for a socially driven expectation that is ecologically unsound.

Case 3. The Queensland Department of Lands has implemented a strategic eradication program for Honey Locust (*Gleditsia triacanthos*), a thorny, leguminous tree that has invaded parts of South-East Queensland. Various treatments using Starane (fluroxypyr) have been identified as the most effective chemical control package for different age classes and field situations. Most of the Honey Locust has been killed. Open niches have been created along riverine systems that are now exposed to reinvasion. Here, it is essential that, in parallel to the control of this pest plant, land managers are advised (using the outcomes of appropriate applied research) of techniques for rehabilitating and restoring the previously invaded areas using appropriate mixtures and densities of native species. Such techniques will need to ensure (as far as practicable) the long-term persistence of appropriate plant communities as part of a land sustainability management strategy.

Each of the foregoing cases could have been more effectively handled had they been placed in a systems framework and key questions asked regarding other factors working at scales above and below the problem identified.

<u>Examples highlighting the need to identify key relationships between land use problems and comprehensive solutions</u>

Case 4. Currant bush (*Carissa lanceolata*) is a native species which has been spreading over the last 15 years in tropical savannas of northern Australia. This has been caused by a change in animal management: Brahman breeds have been used, starting in the 1960s. This has led to higher survival of breeders, which has been enhanced by supplementary feeding. Use of supplements meant that standing dry grass was a valuable resource for maintaining livestock. The beef slump of the 1970s meant that higher stocking rates were generally employed, and the seasons of the mid-1980s allowed higher stocking rates to be maintained. The result was that higher levels of grazing pressure were common and this greatly reduced the fire frequency (10). Currant bush is not particularly fire-sensitive but occasional fires are sufficient to keep it in check.

The solution is to reduce stocking pressure to allow an increase in fire frequency. Chemical control is too expensive. Biocontrol is not appropriate as currant bush is a native. Mechanical treatments were not really practicable (they were expensive and soil limitations were evident).

Case 5. Prickly acacia (*Acacia nilotica*) is an exotic species which has increased markedly in northern Mitchell grasslands since the 1970s. It was declared noxious in 1957. It was planted for shade and fodder in favoured locations around dams and along bore drains. This gave a reliable seed set. During this period cattle largely replaced sheep as the major domestic grazing animal. Consequently, less seed was directly damaged after ingestion and cattle dispersed the seed more widely. Cattle do not graze young plants as heavily as sheep. This change coincided with a series of average to above average rainfall years. Now about 0.5 million ha of land is densely infested with prickly acacia and approximately 6 million ha has some prickly acacia present (11).

The solution is to remove seed producing trees, restrict cattle access to seed producing areas during seed production period, and hold cattle when moving to clean areas. Notably, grazing management (particularly stocking rate) has little role to play when conditions are right as seedling establishment will occur irrespective of pasture condition.

Case 6. Dense infestations of native woody weeds (*Eremophila, Dodonaea, Acacia aneura*) are located throughout the Mulga region. This has been caused through properties being too small, with unrealistic expectations of what production can be achieved. High stocking pressure and no fire has meant that some fire sensitive shrubs are now problems (*Dodonaea, Acacia aneura*). This has resulted in more shrubs and less grass with an increase in dense mulga. This had led to greater pushing of mulga with increased invasion of woody weeds.

The obvious solution of reducing the number of properties (and landholders) by nearly half may not be socially acceptable. Ecologically there needs to be a very substantial reduction in stocking pressure (native, feral and domestic) in conjunction with the establishment of larger property sizes with greater flexibility which carry lower stocking rates. The possibility of using fire as a control is only very opportunistic in this variable climate. There is an urgent need here to save what is left rather than try to reclaim what was lost (11).

Case 7. Rubber vine (*Cryptostegia grandiflora*) has been rated Australia's worst woody weed when selected on a basis for its potential to destroy large areas or acutely threaten an ecosystem over its continental range (12, 13, 14). Rubber vine currently occupies sites throughout 700,000 hectares of Queensland and its estimated cost to the community is $8M per annum in lost production. Of the 150 National Parks susceptible in Queensland, 50% carry rubber vine infestation (15). Rubber vine invasions usually start in flooded areas, move into heavily grazed areas, then into monsoonal thickets, softwood scrubs and brigalow where vegetation community edges are burnt and grazed. The extent of invasion is to some degree a reflection of damage to the vegetation by grazing, fires and flooding. It also reflects the dynamics of rubber vine spread, which is fastest along water courses.

In many cases whole areas of natural vegetation, i.e. gallery forests and open savanna woodland have been totally smothered by this weed. The biological adaptability of rubber vine in the Queensland environment gives it the potential to dominate many ecosystems, destroying most native plant species. Rubber vine is salt tolerant, tends to exhibit vigorous root and shoot growth, produces prop roots in swales and can exploit a wide spectrum of structural niches from shrub forms growing 1-3m high, to climber towers 20m up in a forest canopy.

As a complement to existing control knowledge, urgent research and associated activities as part of a whole systems approach for reducing the impact of rubber vine (12, 16) need to: investigate the relationship between grazing, fire and rubber vine establishment, compile and map the distribution and spread of rubber vine, produce an inventory of vine thickets and riparian zones under threat from rubber vine invasion, develop a heightened awareness throughout the rural community of the conservation significance of vine thickets and riparian zones, avert the spread of rubber vine to the Northern Territory, and maintain and expand the biological control effort, particularly with the rust *Maravalia cryptostegiae*.

These case studies have focussed on specific pest weeds and a systems approach linked to sustainability. Economic indicators can also be applied to a wide range of land use practices to assist in making low-risk environmental and economic decisions that can contribute to the sustainable land use in areas invaded by pest plant species.

CONCLUDING REMARKS

The importation of exotic plant species into Australia remains largely uncontrolled. New pest plants increase linearly as a result of this process (9, 17). Existing pest plants continue to cause substantial environmental degradation. The processes that change habitats outside conservation reserves continue largely unabated.

Most ecosystems are moving into deeper levels of degradation and are usually modified, non-equilibrium or highly fluctuating systems. Fluctuating ecosystems of this type tend to persist in early stages of succession and/or represent ecosystems with degraded resource bases. These conditions provide open niches for weed invasion.

Incomplete understanding of key ecological relationships in these systems diminish the efficacy of chemical, biological, mechanical or integrated approaches to weed control (4). Any reductionist research needs to be placed in context and we need to make sure we are addressing the real constraints. Systems thinking provides an operating framework that helps ensure that the work being done is appropriate. It also provides a 'wide window' view of problems with longer-term social, economic and environmental benefits and insights into key ecological relationships between spatial and temporal characteristics of weeds in ecosystems.

Weed scientists should be able to produce a system diagram before commencing any work on a pest plant. Once this is done, we can plan our research or control. This may be difficult to achieve for biocontrol research, however, this is an issue that demands urgent attention. This approach enhances accountability of weed control research by contributing to comprehensive, more environmentally intelligent weed management. Dedicated collaboration and open, ongoing communication between stakeholders will also be critical if successful outcomes are to be achieved using systems methods.

Arguably, this approach merits vigorous adoption in practice, or at least in providing a framework within which to assess the relevance of more traditional approaches to pest plant research.

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ECOLOGICAL AND ECONOMIC CONSIDERATIONS FOR THE MANAGEMENT OF SHRUB ENCROACHMENT IN AUSTRALIAN RANGELANDS

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Summary. Shrub encroachment problems in rangelands are discussed. An approach to economic control is suggested that is based on seizing windows of opportunity based on ecological understanding of the shrub species. A change in management philosophy is advocated from production orientation towards a balance with resource conservation goals centred on recognition of state and transition paths associated with the underlying pasture resource systems.

INTRODUCTION

The encroachment of native and exotic shrub species into rangeland pastures is imposing significant economic and environmental costs (5). For example, it is estimated that the aggregate income loss for the semi-arid rangelands of NSW and Queensland alone is in the range of $40-$80 million (8). The effective address of these problems is being hampered by two problems. Firstly, many conventional control options (e.g. mechanical clearing, chemicals, range reseeding) appear to be either impractical or uneconomic for broad-area application (6). Secondly, there is a view held by many land managers that alternatives, such as prescribed fire, which do offer scope for economic control (3), also require unacceptable trade-offs between short term production losses and long term benefits (4). This view is reinforced by the strongly held belief in the right of individual landholders to make exclusive decisions concerning rangeland use (7), despite the existence of significant spillovers (e.g. weed spread) that may be imposed on other parties (2).

We argue that in attacking these two problems, opportunities may exist for finding economic control strategies, by exploiting windows of opportunity based on a realistic understanding of the potential states and transition paths associated with the underlying pasture resource base. A change of prevailing management objectives from an exclusive production orientation to accommodate a greater emphasis on resource conservation goals is also advocated.

ECONOMIC CONSIDERATIONS

The few economic analyses of shrub control have related to heavy infestations and shown relatively poor results (5), due largely to high treatment costs relative to productivity gains and the low capital value of rangeland pastures (6). However, many rangeland pastures may carry low levels of infestation with limited immediate economic impact but carry large potential for future damage (2). Management thresholds or switching points may be defined for decision-making purposes where the longer-term economic value of the herbaceous component as fuel to carry prescribed fire for shrub control may be much higher than its short-term (opportunity) value as forage. Similarly, the benefits from future loss-minimisation on a large scale may justify the high cost of treatment on areas from which encroachment may spread (2). In some cases where treatment efficiency is density dependant and cost is inversely related to density, treatment may never be an economic proposition (2,6). It is imperative that land managers appreciate their position when facing thresholds, have a clear recognition of the real economic implications, and act accordingly. Otherwise, they may find that they have passed the threshold before the negative economic effects are actually apparent.

ECOLOGICAL CONSIDERATIONS

Newly emerging non-equilibrium ecological models such as the 'state and transition' model (12) provide valuable insights into rangeland pasture management decisions, including those relating to shrub control. These models, by categorising pastures into different status groups (states) and describing the processes of change (transition paths) between those states, place different options and management thresholds into a clear perspective. A significant departure from traditional models based on concepts of succession and competition, state and transition model logic calls for management based on exploiting windows of opportunity and recognition that transition paths may be asymmetric or unidirectional (12). For example, severe shrub encroachment caused by overgrazing may not be corrected by easing stocking rates. Restoration may require other interventions such as complete spelling and prescribed fire or mechanical/chemical treatment (9). There may also be scope for integrating control methods that in isolation are uneconomic but in combination can yield positive results. For example, sub-lethal chemical applications to mimic shrub mortality in response to fire under low fuel loads may make shrub control requiring episodic burning feasible (10). In many cases, however, once a transition has been made to an undesirable (shrubby) state it may become increasingly difficult to reclaim it in both an ecological and economic sense (5,9).

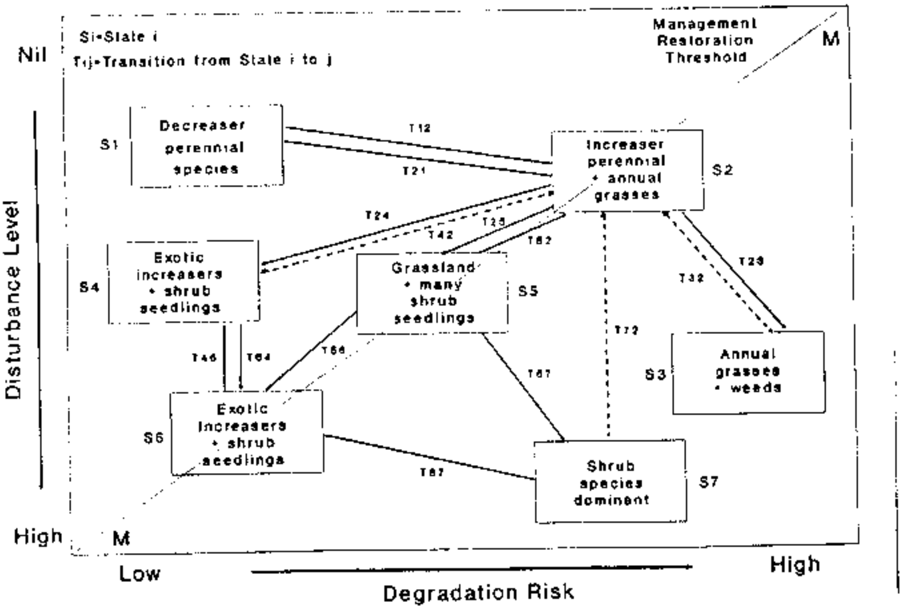

Figure 1. State and transition model for northern woodlands. Boxes represent stable configurations of vegetation. Arrows are transition pathways. Solid lines represent transitions of medium or high probability of occurrence. Dashed lines represent low probability transitions. See Ash *et al.* 1993 for a detailed description of transition pathways.

An example of the state and transition model applied to northern woodlands (2) is shown in Fig. 1. This shows how transitions can be divided into those amenable to management from those requiring restoration by crossing a 'management-restoration' threshold shown by the narrow line MM. The threshold concept raises a key issue of whether a pasture has been 'encroached' upon by shrubs in an economic or an ecological sense. The difference is seen is asking two separate questions; viz. (i) when and how much does forage production decline as weed densities increase; and (ii) when is it no longer economic to restore forage production? From a management perspective the distance between these two threshold points represents a trade-off zone between short and long term benefits and will affect management decisions concerning present and future pasture use and shrub control. This highlights two basic options; viz. (i) to keep open areas open, versus (ii) invoking control measures for restoration; for which the economic decision making processes and evaluations are different. Below the threshold most of the reverse transitions (i.e. to more desirable states) require restoration (e.g. mechanical clearing, chemicals, fire, reseeding) which may be relatively expensive, possibly uneconomic (see above) and ecologically risky (i.e. low chance of success). Above the threshold most transition paths can be effected through simple management strategies (e.g. stocking rate manipulation, fire).

The threshold gap also establishes the need for R&D to define the relationships between weed density and forage production, both short and long term. While these relationships are well documented for agricultural production, they are poorly understood within a rangeland context, with most emphasis having been placed on the biology of the key shrub species (6). As long as principal benefits of shrub control remain tied to animal productivity considerations, and economic factors weigh heavily in the decision processes of individual landholders, these relationships will be of extreme importance. The need for R&D to examine the economics of excluding shrub populations from rangeland pastures, rather than attempting to remove them, becomes a real issue.

CHANGING MANAGEMENT ORIENTATION

Management objectives dominated by a focus on assumptions of economic rationalism (e.g. profit or wealth maximisation) imply production supremacy in decision-making. This orientation is appropriate for states above the management-restoration threshold which are primarily production states. The primary goal orientation and legitimate use for planning is production/exploitation. However, effective management of pasture units in states lying below the management-restoration threshold (MM) will require a conservation/restoration supremacy or at best a higher weighting on resource conservation objectives than is evident in many cases at present. These are primarily conservation states where orientation and legitimate use is conservation/reclamation/restoration. Herbage should be managed in a conservative manner and managers should be fully cognisant of that fact. This is consistent with an emerging view that a stronger land care ethic should be ingrained into rangeland management values (11).

Rangeland management units (e.g. paddocks or whole property) typically comprise a mix of pasture resources in different states. For example, in the northern woodlands context, a manager may have access to country that is representative of many of the states in Fig. 1. In these circumstances management focus should be shifted from production to resource conservation goal orientation spatially with different parts of the management unit identified by their current productive state, shrub risk potential and/or restoration opportunity and managed accordingly. Appreciative and pro-active management can shift pasture resources between states and/or retain pastures in desirable states, particularly those that are free of shrub problems. To achieve this it is essential that managers recognise that windows of opportunity and monitoring needs are different for the different states. Moreover, it is not essential to rigidly adhere to a given objective. Units that are targeted for shrub control may, under runs of good seasons, produce herbage in excess of that needed for effective control. A rational decision could be taken to opportunistically graze the excess. Open pastures with minimal shrub populations may be burnt under similar circumstances to preserve their status. We are simply advocating that managers recognise the states and transitions associated with their pasture resources and appreciate the implications for resource allocation decisions. Under this scenario the prevailing mindset changes from exploitation to conservative management of the system.

CONCLUSION

Shrub encroachment problems in extensive rangelands impose significant losses on individual landholders and the wider community. Once these problems have arisen, control options are generally restricted by ecological opportunity and economic considerations. Moreover, a strong production orientation in land use decision making may reinforce the encroachment problems and promote a lack of concerted action to overcome them.

We are suggesting that management of rangeland pastures requires an intelligent balance between production and resource conservation objectives. Land managers should have a clear understanding of both the economic and ecological implications of their actions in both the short and longer terms. With such a balance there is more likely to be a desirable shift in management orientation to one that is consistent with sustainable production over time.

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ARE WE JUSTIFIED IN CONSIDERING FIREWEED (*SENECIO MADAGASCARIENSIS*) AN EXOTIC?

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"In the early times of a colony, there is comparatively little difficulty in distinguishing the colonists from the native species; but as the surface of the land becomes artificially disturbed, the habits of all its plants are influenced, - the endemic plants are driven from their native places, and take refuge in hedgerows, ditches and planted copses, and from there associating with the introduced plants, are apt to be classed in the same category with them."

J.D. Hooker 1860

Summary. Prior to 1981, fireweed was recognized as part of the native Australian *Senecio lautus* complex. Since then it has been recognized as *Senecio madagascariensis*, an exotic of Malagasy or southern African origin. It appears the change of status, from native to exotic, was based essentially on a single identification by a foreign Compositae expert. I believe there is little or no empirical support for the hypotheses that fireweed is of Australian or Malagasy origins and that the alternative possibilities require adequate testing. Bract number and achene hairiness are the morphological characters used to support the hypothesis that fireweed is the exotic *S. madagascariensis*. However, there appears to be as much variability in both characters within the Australian *S. lautus* complex as there is within the *S. madagascariensis* complex. Differences in chromosome numbers have also been used to justify an overseas origin for Australian fireweed. However, the chromosome numbers in the complex in Madagascar and southern Africa have never been determined.

INTRODUCTION

Fireweed is a major weed of coastal pastures in New South Wales (4, 34). Fireweed is very similar to members of both the native Australian *Senecio lautus* complex and members of the southern African *Senecio madagascariensis* complex. Herbarium specimens of fireweed in New South Wales date back to 1918 (34) and for most of this century fireweed has been considered a weedy form of *S. lautus* (1, 36). However, because of apparent differences in bract number and habit, P.W. Michael in 1980 sent specimens of fireweed to O.M. Hilliard, a South African Compositae taxonomist. Hilliard identified the specimens as *Senecio madagascariensis*. Since 1981 Australian fireweed has been recognized as *S. madagascariensis* (27).

The 1981 name change instituted a reassessment of some of the basic assumptions pertaining to fireweed. In particular the weed was seen as an exotic instead of a native. There was no longer any interest in understanding it's possible affinity with the native *S. lautus* complex (c.f.1). Biological control using insects and pathogens from Madagascar and southern Africa became a possibility (23, 24) and a biocontrol program commenced in 1989. In addition, interest has been generated in predicting fireweed's potential spread based on BIOCLIM and CLIMEX predictions from the overseas distribution of *S. madagascariensis* (9, 34).

Thus the assumption that Hilliard correctly placed fireweed in the appropriate taxonomic entity has become a central premise of recent studies and biocontrol efforts. Weed biocontrol has a history of problems associated with the mistaken identity of weed species (13, 26, 31, 33). All scientific efforts are based on theory with a particular methodology and particular assumptions (7). Given the importance of the change of status for fireweed from native to exotic in 1981, it is perhaps worth scrutinizing the assumptions on which Hilliard based her identification. In the following section I do this through a discussion of differences in morphological and genetical concepts of species.

Platt (30) and Cousens (8) have criticised the methodology modern biologists' generally employ to arrive at their conclusions, suggesting that we are principally interested in confirming our suspicions rather than testing alternative hypotheses. Platt (30) advocates the adoption of multiple working hypotheses. In employing this methodology I suggest at least four hypotheses about the identity of fireweed are worthy of testing.

DISCUSSION

Understanding and defining species.

"It is quite evident .. that even those who profess to hold a morphological species concept base their taxonomic decisions ultimately on the biological criterion of interbreeding. Degree of morphological difference is completely useless as a yardstick for species status unless it is applied in conjunction with such biological criteria"

Mayr 1963:33

Botanists and zoologists generally agree that species are kept distinct from one another because they are sexual and do not interbreed; that is, there is no gene flow between them (6, 25, 29). Indeed, the fundamental basis of any sexual species is genetic and a species can be best defined as "a field for gene recombination" (5). The unique genetic "make-up" of each species is commonly reflected in morphological differences and thus for the most part taxonomists using morphological characters can adequately distinguish between species and classify them according to morphological characters. However, because of phenomena such as sexual dimorphism, sibling (or cryptic) species in insects (28) and plants (22) and the prevalence of ecotypes in plants (reviewed in 10) morphological difference is not inevitably a useful indicator of "species status". Also using an essentially morphological concept of species can lead to ambiguity in the definition of a species' "limits". For example *Senecio* taxa that are treated as species would be treated as subspecies in other genera of the Compositae (13).

Hilliard's book Compositae in Natal (South Africa) (16) includes five species in the *Senecio madagascariensis* complex, *S. madagascariensis*, *S. inaequidens*, *S. burchellii*, *S. skirrhodon* and *S. harveianus*. The five species are defined arbitrarily principally on morphological characters (16, 17). I found Hilliard's classification very difficult to use in the field in South Africa. In particular, I found that differences in plant age within a single species could account for the differences described by Hilliard between *S. madagascariensis* and *S. inaequidens*. Also, I found *S. inaequidens* was very common as a weed in winter pastures in the Ixopo - Richmond area at altitudes below the 1400 metres limit Hilliard used to delineate the two species ranges (16). L. Vincent (South African Compositae taxonomist, University of Witzwatersrand) confirmed my identifications. I also found it difficult in some situations to distinguish *S. madagascariensis* from *S. skirrhodon*, in particular, and I quote Hilliard (16): "specimens of *S. madagascariensis* from near the sea grade into *S. skirrhodon* which is possibly no more than a maritime form of *S. madagascariensis*".

In plants, morphologically or physiologically different forms, called ecotypes, can be found in association with different microhabitats (reviewed in 10). The situation I observed with *Senecio madagascariensis* in Madagascar appeared similar to the situation with hawkweed, *Hieracium umbellatum*, studied in detail by Turesson (35). In Madagascar I transplanted prostrate fleshy dune plants, *S. madagascariensis* variety *crassifolius* (19), growing on the sand dunes at Lanirano (near Fort Dauphin) into pots in my sheltered garden in Toliara and after a period of several months these plants became erect and their leaves membranous. Turesson's experiments showed that the four morphologically distinct ecotypes of hawkweed which exist in association with sand dunes, sandy fields, seaside cliff faces and forests respectively are morphologically identical when cultivated together in a garden situation. In these instances morphological differences appear to reflect phenotypic not genotypic differences and it is reasonable to conclude that the ecotypes represent one potentially interbreeding species.

I have no field experience with fireweed and the *Senecio lautus* complex in Australia. The detailed genetic and cultural studies of Ali (1, 2, 3) resulted in the description of four subspecies of *Senecio lautus*. However, my colleagues and comments in Ali (3) suggest that many more subspecies may exist. Jessop and Toelken (21) suggest Ali's four subspecies are not clearly defined "and require re-examination by conventional taxonomic methods". This statement suggests these authors would prefer we regress to the use of Morphological Species Concepts!

Ali (3) based his interpretation of the *S. lautus* complex on the Biological Species Concept, referred to in the remainder of this discussion as the Isolation Concept of species, after Paterson (29). Interpretation of results based on the theoretical framework provided by the Isolation Concept of Species has proven difficult because Isolating Mechanisms are difficult to define (6, 15, 29). The Recognition Concept of species provides an alternative theoretical framework. The Recognition Concept emphasises the need to understand the fertilization mechanism which individuals of the same gene pool (i.e. conspecifics) possess as an adaptation to ensure fertilization (29). Ali (2) established that individual plants within the *S. lautus* species complex are out-breeding and hypothesized that cross pollination occurred probably through moths of the families Arctiidae and Hypsidae; he cited observations by L. Schmidel (2). However, Ali (2) qualifies this by stating that the various subspecies occur in extremely diverse habitats inferring that pollinators in these different habitat types would be different. More information from appropriately designed observations would be needed to ascertain whether gene flow occurs among the "subspecies" in their different and diverse habitat types. In particular the likelihood of shared or different insect pollinators should be resolved, before conclusions regarding species status could be reached from the perspective of the Recognition Concept of Species.

Testing multiple hypotheses. Science is supposedly about objectively verifying hypotheses. Yet how interested are we as weed scientists in testing hypotheses at all? Since 1981 we have accepted the authority of a single identification by a taxonomist unfamiliar with the Australian flora, who using a Morphological Concept of species changed basic assumptions pertaining to an important weed species in a difficult group, evidently very closely related to a native species complex. This authority has been respected and the single identification never verified in one unpublished dissertation (34) and has similar status in some other areas of current research.

The following hypotheses have been formulated principally to indicate that there are several alternative possibilities. These hypotheses have been formulated using the currently recognized morphologically defined "species" and I see this as a major limitation - but it is a start.

Weed status

1. Fireweed is *S. madagascariensis*. This hypothesis has been supported on grounds of morphological similarity. However, there are differences in the number of ray corolla resinous lines, height and life cycle between fireweed in Australia and *S. madagascariensis* in South Africa (compare Hilliard 1977 with Sindel 1989 and NSW Agfacts). *S. madagascariensis* in Madagascar usually has only 7 or 8 ray florets and in this regard is different to both Australian fireweed and *S. madagascariensis* in South Africa but is similar to the South African plant referred to as *Senecio burchellii* (personal observations).

Differences in chromosome number between fireweed and the *S. lautus* complex have also been used to support the above hypothesis (34). However, the chromosome number of members of the complex in southern Africa and Madagascar have not been determined (Hilliard & Vincent, personal communications).

If fireweed is *S. madagascariensis* it is reasonable to expect to be able to find species-specific biological control agents in South Africa and Madagascar.

2. Fireweed is *S. inaequidens*. This species is as morphologically similar to fireweed as is *S. madagascariensis* and is more similar to fireweed in life cycle (compare Hilliard 1977 with NSW Agfacts).

S. inaequidens normally occurs above 1400 metres in South Africa (16). *S. inaequidens* is naturalized in southern Europe and Great Britain (16). It does not occur in Madagascar. A predicted distribution of fireweed using BIOCLIM or CLIMEX and the overseas distribution of *S. inaequidens* would be very different from a prediction based on the overseas distribution of *S. madagascariensis*.

If fireweed is *S. inaequidens* then it is reasonable to expect we could find species-specific biological control agents in South Africa and perhaps southern Europe, but not in Madagascar.

3. Fireweed is part of the *Senecio lautus* complex. Although Ali (2) did not refer to fireweed by name he recognized a weedy form of *S. lautus* which he suggested was a result of "mingling of genoecodemes", suggesting fireweed is of hybrid origin. Carson (6) gives examples of other species with vigorous and fully fertile natural hybrids which appear to maintain their genetic integrity through natural selection relating to newly-formed habitats.

If fireweed is of hybrid origins then the chances of finding specific biocontrol agents in southern Africa and Madagascar are much reduced.

4. The *S. madagascariensis* and *S. lautus* complexes include one or more species which are conspecific. The morphological variability within the *S. lautus* complex described by Jessop and Toelken (21) parallels the variability within the *S. madagascariensis* complex described by Hilliard (16, 17) and Humbert (19). It is interesting that bract number in both complexes varies from 12 to 21.

There are numerous examples in the literature (32, 11) of plant species with populations which have been separated geographically for tens of millions of years but which have not diverged morphologically and which are still interfertile. The concept of continuous change and adaptation in spatially separated populations is an inherent, but flawed, assumption of the Isolation Concept of Species, on which much of modern evolution and ecology is based (12, 29, 37). A result is that biologists expect differences among conspecific populations collected from widely different geographic regions.

There are remarkable morphological and habitat similarities between the dune "species" in Madagascar, *Senecio madagascariensis* variety *crassifolius*, South Africa, *Senecio skirrhodon*, and Australia, *Senecio lautus* subspecies *maritimus*. And my observations in Madagascar suggest *S. madagascariensis* variety *crassifolius* is an ecotype of *S. madagascariensis* variety *madagascariensis*, in accordance with Humbert (19).

In conclusion. Weed scientists interested in understanding a plant's population dynamics may dismiss the importance of "identity". However, it has been recognized to some extent (20, 14), and is fundamental to the Recognition Concept of species (29, 37), that an understanding of the specific adaptations of a species can be best understood through an understanding of the environment in which it speciated. For example, if fireweed is a species of sand dune origin, then an understanding of the adaptations possessed by dune species in general, and fireweed in particular, would enable us to understand better the population dynamics of fireweed. In any case, any ecological study based on a morphologically defined species must be of very limited value if this taxonomic entity does not correspond with the genetical species.

Current research efforts may be soundly based, but we cannot be certain because an underlying assumption may not be valid. Given the importance of fireweed and the importance of identity for successful biological control, multiple hypotheses should be tested using appropriately designed experiments to understand species in the *S. lautus* and *S. madagascariensis* complexes.

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INSECTICIDE EXCLUSION WITH CARBOFURAN DEMONSTRATES THE EFFECTIVENESS OF *HETEROPSYLLA SPINULOSA* AS A BIOLOGICAL CONTROL AGENT FOR *MIMOSA INVISA* IN NORTH QUEENSLAND

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Seed production, growing tip elongation and growth rate were compared between an insect-infested and insect free clump of giant sensitive plant, *Mimosa invisa*, at Mena Creek in north Queensland. Carbofuran applied at 45 kg a.i./ha effectively excluded establishment of *Heteropsylla spinulosa*. *H. spinulosa* reduced seed production by 80% (average number of seeds per pod no insects 60: insects 12), growing tip elongation by 77% (average stem length between the first and second fully expanded leaves no insects 1.65 cm: insects 0.38 cm), and the growth rate of tips by 50% (stem elongation from tagged tips measured after a 12 week period no insects 1.5 m: insects 0.7 m).

Insect exclusion clearly demonstrated the impact of *H.spinulosa* on *M.invisa* in north Queensland pasture infestations and supported other data collected over four years. Field exclusion experiments are an under-rated post-release technique for quantitatively evaluating the effect of introduced biological control agents. This technique readily segregates the impact of the insect control agent(s) from other variables affecting weed growth such as climate and nutrition.

THE SIGNIFICANCE OF AMARANTHS AS WEEDS OF CROPS IN TASMANIA

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A survey of DPIF staff, growers, vegetable processors and agricultural consultants provided information on amaranth occurrence in Tasmania. These groups see Powell's amaranth, *Amaranthus powellii*, as the major amaranth weed problem, with redroot amaranth, *A. retroflexus*, as a minor problem. The most serious occurrence of Powell's amaranth was in green bean and summer brassica crops grown on Tasmania's north-west coast. In Southern Tasmania, Powell's amaranth was reported as a minor problem. The north-east and central regions of Tasmania did not have any major problems with amaranth but recognised it as a potential weed problem. The main form of amaranth seed transmission in the north-west of the state was thought to be via harvesting equipment and other farm machinery. A number of strategies , including inter-farm hygiene are being considered by the DPIF to control Powell's amaranth in green bean and summer brassica crops.

CIRSIUM ARVENSE SELECTIVITY CONTROLLED IN PASTURE BY A *SCLEROTINIA SCLEROTIORUM* MYCOHERBICIDE

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Field trials were conducted in Canterbury, New Zealand, to test an experimental mycoherbicide against *Cirsium arvense*. A rudimentary mycelium-on-cracked-wheat preparation of *Sclerotinia sclerotiorum* applied to the foliage of pasture populations of *C. arvense* in the spring, caused catastrophic reductions in densities of both aerial shoots and root buds in the season of application. The two dominant pasture species (*Lolium perenne* and *Trifolium repens*) were unaffected by the pathogen. These results indicate that the potential of this pathogen as a control agent for this weed in grass/clover pastures is very high. However the crucial need for a energy source and hence considerable mass in any mycelial formulation of this pathogen presents a potential problem to the formulator. In the experiments in Canterbury, application rates of 370 to 500 kg/ha were used which were much too high to be commercially acceptable. Application rates were modelled using data on *in vitro* leaf infection success rates of mycelium-in-milled-wheat granules of varying size and varying mycelium concentration. This analysis revealed that field application of 20 kg/ha of granules 0.5 mm in diameter containing 1.5 to 3.6 g dry mycelium/kg (0.15 - 0.36% ai), would give one viable granule/cm^2 of treated surface area. The field success rates of such granules, and the density required to kill a shoot, are not yet known. The clear challenge to the formulator is to produce an inoculated energy source (granule) that has a very high probability of infecting the thistle in the field. Acceptably low field application rates, and commercialisation of the pathogen, would then be possible.

POST-EMERGENCE GRASS CONTROL IN LUPINS

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The relative effectiveness of post-emergent grass herbicides from both the aryloxyphenoxypropionate and cyclohexanedione families for the control of volunteer cereals and ryegrass was evaluated over three years near Rutherglen, North-East Victoria, Australia.

Results showed that haloxyfop (52 g/ha), quizalofop-p-ethyl (24 g/ha) and clethodim (60 g/ha) gave better control of wheat than fluazifop-p (53 g/ha), proquizalofop (40 g/ha), and cycloxydim (50 g/ha). For oats proquizalofop (40 g/ha), fluazifop-p (80 g/ha), cycloxydim (100 g/ha), quizalofop-p-ethyl (24 g/ha) and haloxyfop (52 g/ha) gave similar control to each other and better control than diclofop-methyl (563 g/ha). Barley was well controlled by clethodim (120 g/ha), fluazifop-p (80 g/ha), quizalofop-p-ethyl (24 g/ha) and haloxyfop (52 g/ha). The best control of triticale was given by clethodim (120 g/ha), cycloxydim (50 g/ha), quizalofop-p-ethyl (24 g/ha) and haloxyfop (52 g/ha). Sethoxydim (93 g/ha) and clethodim (60 g/ha) gave superior control of annual ryegrass (*Lolium rigidum* cv Wimmera) than haloxyfop (31 g/ha), proquizalofop (40 g/ha), diclofop-methyl (375 g/ha), cycloxydim (100 g/ha), quizalofop-p-ethyl (24 g/ha) or fluazifop-p (53 g/ha), listed in descending order of effective control.

THE ALLELOPATHIC IMPACT OF GOOSEFOOT ON CROPS AND PASTURES

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Goosefoot (*Chenopodium pumilio*), a widespread weed of southern Australia, was examined for its allelopathic impact on crops and pastures following reports of massive establishment problems in goosefoot residues in Western Australia. Germination suppression from 0-100% and growth inhibition from 70-90% were recorded for the pasture species. However, the overall impact on wheat and lupins was more drastic because of their greater sensitivity. Wheat was less susceptible than lupins, probably because of its shorter fibrous root system. With lupins, the rapid growth of its tap root is thought to enhance the uptake of the rain-soluble allelochemicals being leached down the soil profile. This explanation was supported by a field experiment which showed that shallow seeding of wheat into the goosefoot residues could overcome the allelopathic impact.

HYDROCOTYLE RANUNCULOIDES IN THE CANNING RIVER, WESTERN AUSTRALIA

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The floating aquatic weed *Hydrocotyle ranunculoides* infested the lower reaches of the Canning River in Perth, Western Australia between 1983 and 1993, probably as a result of careless disposal of aquaria waste. Hydrocotyle has not previously been recorded as a serious weed in Australian waterways although a close relative, *H. bonariensis*, has caused problems in Singapore, southern USA and South America.

In November 1991 a removal program was successful in removing the bulk of the weed but due to the lack of follow-up treatment the mats regrew.

In the absence of a recognised control protocol a working group of state and local government agencies and special interest groups was formed to develop an effective control program. An integrated strategy was adopted, in the first instance a short term program to physically remove the bulk of the weed, and a longer term program aimed at eradication. The river was cleared of the weed during the first phase using a combination of physical and chemical methods in 1993 at a cost estimated at $150,000.

DISTRIBUTION OF SILVERLEAF NIGHTSHADE *(SOLANUM ELEAGNIFOLIUM)* IN THE SHEEP/WHEAT BELT OF NEW SOUTH WALES

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Silverleaf nightshade (*Solanum elaeagnifolium*) is a major perennial weed of New South Wales, Victoria and South Australia. It competes with summer crops and pastures and can reduce winter crop production by soil nutrient and moisture depletion during seedbed preparation. All parts of the plant, particularly the fruits are toxic to grazing livestock. Silverleaf nightshade is difficult to eradicate due to its extensive root system. A survey conducted in 1977 showed there was 20,000 ha of land infested with silverleaf nightshade in New South Wales.

In spring 1992 a survey of the sheep/wheat belt of New South Wales was conducted to ascertain the distribution and density of infestation of silverleaf nightshade. The survey was done on a local government area basis using NSW Agriculture's district agronomists. The results showed a total of 139,000 hectares of land was infested with the weed (16,000 ha dense infestation). This is nearly a seven fold increase in the area infested since 1977.

HOST SPECIFICITY OF THE BRUCHID *MIMOSESTES ULKEI*, AS A BIOLOGICAL CONTROL AGENT FOR *PARKINSONIA ACULEATA* IN AUSTRALIA

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In host specificity tests, the North American seed beetle *Mimosestes ulkei* was found to be a host specific biocontrol agent for the woody weed *Parkinsonia aculeata*.

M. ulkei was imported from Arizona, USA for host specificity testing in quarantine. Multiple choice oviposition tests were carried out on pods of a range of legumes and on seeds of a range of non-legumes. Forty-nine plant species were tested, with *P. aculeata* controls. Egg and larval development on test pods was studied.

Oviposition occurred on pods of 19 legume test species. Many more eggs were laid on *P. aculeata* pods than on the test species' pods. First instar larvae penetrated the seed coats of 11 test species, but either retreated from the seed or made very short tunnels and died *in situ* without further development. Some pods had barriers preventing larvae from reaching seeds. Seeds attacked by larvae had mechanisms that discouraged feeding or actively killed larvae so that none were able to develop to become adults. Adults developed only in *P. aculeata* seeds.

Failure of *M. ulkei* to develop in any test plant seeds showed that it is specific to *P. aculeata* and safe to release in Australia. The Australian Quarantine and Inspection Service has approved *M. ulkei* for field release.

PROPOSAL TO ESTABLISH A NATIONAL BUFFER ZONE TO PREVENT THE WESTWARD MOVEMENT OF RUBBER VINE *(CRYPTOSTEGIA GRANDIFLORA)* IN AUSTRALIA

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Rubber vine *(Cryptostegia grandiflora)* is now one of the most damaging weeds in Australia. It occupies over 600,000 ha of northern Queensland and is spreading rapidly westward. *Cryptostegia grandiflora* is not known to occur in the Northern Territory or Western Australia. However, it does have the potential to invade 58 million hectares of Northern Australia, including Arnhem Land, Kakadu and the Kimberly's.

This poster presentation will illustrate the importance of establishing this national buffer zone and why the Northern Territory/Queensland border region is an ideal area for its implementation.

DIFFERENTIAL GROWTH AND ANATOMICAL CHARACTERISTICS OF RICE AND BARNYARDGRASS UNDER VARIOUS CROPPING PATTERNS

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This study was conducted in a greenhouse to see if there are some differences in growth and anatomical characteristics between rice *(Oryza sativa)* and barnyardgrass *(Echinochloa crus-galli)* under different cropping patterns, dry directed condition, water directed condition and transplanting condition. At 3, 5, 7, 10, 15 and 20 days after seeding or transplanting (DAS/T), plants were harvested and their growth and anatomical characteristics were examined. Difference in growth characteristics including plant height, root length, shoot and root fresh weight, leaf stage and number of root between rice and barnyardgrass was greater under dry condition than those under water condition and those of barnyardgrass was greater than those of rice under both dry and water directed condition, while rice was much greater than those of barnyardgrass under transplanting condition. Mesocotyl was formed in only barnyardgrass and its length increased with increased depth of seeding. In differential anatomical characteristics at 5 DAS/T, epidermal cell arrangement of stem and root in transverse sections was regularly dense under dry conditions, while were not regular and aerenchyma cells were well developed under water condition, and there were great difference between rice and barnyardgrass. Leaf blades were thicker in rice than in barnyardgrass, in barnyardgrass grown under dry than water conditions, and in direct seeded than in transplanted rice.

EVALUATION OF A TRIAZINE IMMUNOASSAY KIT

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The usefulness and limitations of a commercially available immunoassay based kit for determining triazine herbicide residues in soils and waters have been assessed. Results obtained using kits were compared to conventional chemical analysis results for the same samples. The kits are potentially useful as screening tools for herbicides in water samples. Results for soil samples tested to date were less satisfactory, because of problems with quantitation and possible background effects.

MANAGEMENT STRATEGIES TO REDUCE HERBICIDES IN RICE FIELD TAIL WATERS OF THE SACREMENTO VALLEY

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California rice is irrigated with surface waters through a network of supply and drainage canals. Excess water from 160,000 ha of rice is returned to the Sacremento River and its tributaries for downstream uses. Pollution from rice herbicides raised public concerns in the late 1970s and early 1980s when fish kills and off-tastes of potable water were attributed to molinate and thiobencarb respectively. The purpose of these studies was to develop and implement management strategies to mitigate downstream pollution by rice field herbicides. Two novel rice irrigation systems, water recirculation (WR) and static water (SW), were compared to conventional flow-through irrigation systems with respect to herbicide degradation and off-field movement. Two additional systems, gravity tailwater recapture (GTR) and water ponding (WP), were also introduced to growers to ameliorate off-site herbicide pollution. In the decade from 1982 to 1992, the evolution and adoption of these systems reduced the mass flow of molinate in the Sacremento River from 18,465 kg to 56.6 kg. Similarly, thiobencarb mass flow was reduced from 2,317 kg in 1985 to 0 kg in 1992.

BAMBOO - POTENTIALLY USEFUL PLANTS AND POTENTIAL WEEDS

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In many other countries (South America, Africa and Asia) bamboo is not generally considered a problem plant to the extent that it is here in Australia. Bamboo has an existential place in the lives of people. Bamboo is harvested for food, fibre, timber and as a raw material for art and craft. Where bamboo has a long cultural, spiritual, functional and amenity value it can hardly be considered a weed. In this case its most active predators are people.

In Australia bamboo has no functional profile in our everyday lives or in the non-aboriginal cultural heritage of this country. Adding all bamboo plants to the growing list of declared weeds will not address the ignorance and misunderstanding in our attitudes towards bamboo. Some strategic approaches to increasing awareness of these plants are:

(i) identification and mapping of bamboo species in Australia;
(ii) species identification charts for community, nursery and agricultural industries and quarantine inspectors;
(iii) field trials for potentially useful species including rhizome controls; and
(iv) standardised weed hazard rating for potentially rampant species, based on field trials and regional climatic criteria.

VARIATION OF SEED DORMANCY IN WEED WILD RICE *(ORYZA)* SPECIES

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Wild rices (*Oryza* spp.) are a problem in the production of rice in the direct-seeding areas in tropical countries. Seeds of wild rice shed readily at maturity and show a deep dormancy, enabling survival for extended periods under unfavourable conditions. The nature and variations of dormancy in 10 strains of wild rice and 3 strains of weedy wild rice collected from various countries were determined.

Wild species of rice were grown in the greenhouse at day and night temperatures of 31°C and 26°C. All the seeds of wild rices were found to be dormant and as heat treatment was prolonged or when unhulled, germination percentage was raised. Seeds of *O. rufipogon* from India, Myanmar, and Malaysia and *O. breviligulata* and *O. brachyantha* from West Africa showed extremely deep dormancy, whereas weedy wild rices which were considered to have absorbed genes from cultivated rice through natural hybridization showed higher germination rate. Dry condition was found to be influential in breaking dormancy of wild rice seeds regardless of the temperature range, whereas moist condition was unfavourable. Seed dormancy among the same species of wild rices varied greatly with the country of their origin.

HERBICIDE USAGE RECORDING SYSTEM

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In a climate of increasing public concern over pesticide use and litigation, accurate and easily accessible application data is essential to the land manager.

The Herbicide Usage Recording System (HURS) aim is to provide a fast, easy to use and comprehensive record of herbicide applications to predominantly linear land reserves such as railways, roads, irrigation channels and power and communication utilities.

The HURS system provides this on two levels. It is primarily a computer data base that will provide key information. In addition by the use of the unique reference number generated by HURS, the actual paper report produced by the spray operator may be quickly accessed for more detailed information. This provides the manager with a powerful tool to review the success of past applications and answer queries confidently.

The programme was originally prepared by the Public Transport Corporation to record all application of herbicide over the main-line rail network. However, it is envisaged that the system can be easily modified to suit other land management systems.

PHOTODEGRADATION OF BENSULFURONMETHYL HERBICIDE UNDER SIMULATED ENVIRONMENTAL CONDITIONS

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Photodegradation appears to be an important step in the transformation of herbicides applied to wetland paddy as most herbicides are applied at the time of transplanting. Bensensulfuron-methyl herbicide (methyl α-[[3-4,6-dimethoxypyrimidin-2-yl] ureido]sulfonyl-0-toluate; BSM), a common herbicide in paddy fields of Japan, has unique physicochemical properties, for example, its solubility in water is strongly dependent on pH (2.9 ppm at pH 5.0 to 1,200 ppm at pH 8.0 at 25°C). Th pH of water in paddy fields varies considerably (6.4 to 8.9) within a single day.

We studied photodegradation process of BSM under simulated environmental conditions. After irradiating aqueous solutions of BSM with varying pH and photosensitizers in a spectro-irradiator, photodegradation products of the herbicide were analyzed by liquid chromatography and mass spectrometry. Photodegradation was confirmed by changes of UV absorption spectra under acidic conditions and in the presence of photosensitizers.

SELECTIVE MODE OF ACTION OF PYRAZOSULFURON-ETHYL AMONG RICE CULTIVARS AND *CYPERUS SEROTINUS*

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Pyrazosulfuron-ethyl is a sulfonylurea herbicide for the control of most broadleaf and cyperaceous weeds in paddy rice. The growth of root and shoot was suppressed more strongly in *Cyperus serotinus* than in rice grown in a water culture containing pyrazosulfuron-ethyl. *In vitro*, the activity of acetolactate sythase (ALS) from each organ of both plants was highly and similarly sensitive to pyrazosulfuron-ethyl. The activity of ALS extracted from plants previously treated with the herbicide was more reduced with elapsed time in roots and shoots of *C. serotinus* after treatment. In rice the reduced activity of ALS in treated roots and shoots was remarkably recovered as a function of time after treatment. Among tested rice cultivars, *indica* type cultivars were generally more tolerant to pyrazosulfuron-ethyl than *japonica* type cultivars. Inhibition of ALS activity in each organ was similar in degree between *indica* and *japonica* type cultivars *in vitro*. The results suggest that the primary site of action of pyrazosulfuron-ethyl is ALS, and that its selectivity depends on the difference in degree of inhibition on ALS activity *in vivo*, which could be caused by the different ability in inactivation of pyrazosulfuron-ethyl.

THE MECHANISM OF ACTION OF DIMEPIPERATE ON SEVERAL OTHER HERBICIDES IN RICE SEEDLINGS

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The interactions between the thiocarbamate herbicide, dimepiperate (S-(α, α-dimethylbenzyl) piperidine-1-carbothioate) and 7 compounds of herbicides, and the effects of dimepiperate on absorption, translocation, and metabolism of [^{14}C]labelled bensulfuron methyl, oxyfluorfen, clomeprop and pyributicarb simultaneously applied to the early stage of rice seedlings were examined. Their interactions were evaluated based on Colby's and/or the Isobole method. The data indicated that there were antagonistic effects between dimepiperate and all the herbicides tested except for pretilachlor. Thus, the safening effect of dimepiperate on the rice seedlings was confirmed. Dimepiperate did not affect translocation of and metabolism of all [^{14}C]labelled herbicides, whereas it decreased their absorption in rice plants. The decrease in the herbicide absorption seemed to contribute to the safening effect of dimepiperate.

The safening effect of dimepiperate was clearly demonstrated to a wide range of the chemicals with different modes of action.

MECHANISM OF SELECTIVITY OF DIPHENYL ETHER HERBICIDE OXYFLUORFEN

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The selectivity mechanism of oxyfluorfen [2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-trifluoromethylbenzene] among several plant species was studied. Rice and corn were tolerant and absorbed less oxyfluorfen than tomato, cucumber and buckwheat. Degradation of ^{14}C-oxyfluorfen in the susceptible plants was very limited. Large amounts of protoporphyrin IX (Proto IX) accumulated in the herbicide-treated plants, however, the profile of the accumulation was different among the species. Protoporphyrinogen IX oxidase (Protox) was very susceptible to oxyfluorfen. I50 concentration of Protox activity from different plant species ranged from 1.4 nM to 30 nM. The activity of endogenous antioxidative enzymes was also different among the tested plants and rice had a higher activity than the others.

TOLERANCES OF OAT AND TRITICALE CULTIVARS TO HERBICIDE

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The tolerances of cultivars of oat (Cooba, Coolabah, Dalyup, Echidna, Bandicoot and Mortlock) and triticale (Muir, Madonna, Currency and Tahara) to post-emergence herbicides under weed-free conditions were examined in the field in 1991 and 1992 at Wagga Wagga. Herbicides were applied at standard recommended (1XR) and twice recommended (2XR) rates and grain yield was used as a measure of tolerance.

At both rates of application, diuron, chlorsulfuron and dicamba plus MCPA were safe on all oat cultivars. Grain yields were reduced 10% in Mortlock and Dalyup in 1991 by 1XR of bromoxynil, diflufenican plus MCPA and diflufenican plus bromoxynil. Dalyup was also sensitive to terbutryne plus metsulfuron.

In 1991, triticale cvs Muir and Tahara had grain yields reduced 12% from the 1XR of diclofop-methyl, and by 19% (Tahara) and 38% (Muir) from 1XR of metsulfuron-methyl. Currency and Madonna were both sensitive to terbutryne plus triasulfuron at 1XR in 1992. All triticale cultivars were tolerant of tralkoxydim, chlorsulfuron, dicamba plus MCPA, bromoxynil, diflufenican plus bromoxynil, diflufenican plus MCPA, and terbutryne plus MCPA.

Significant differences in the tolerances of oat and triticale cultivars to recommended rates of herbicides was demonstrated and further studies are in progress on a wider range of cultivars and herbicides.

DIFFERENTIAL COMPETITIVE ABILITY OF WINTER CROPS TO ANNUAL RYEGRASS, *LOLIUM RIGIDUM*

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A field comparison was made of the competitive ability of a range of winter crops (wheat, barley, oat, lupin, field pea, triticale and canola) against annual ryegrass, *Lolium rigidum*. The crops were sown at standard densities. Annual ryegrass was sown immediately after the crops by broadcasting seed and raking it into the surface of the soil to achieve a density of 300 plants/m^2 in all crops. Two cultivars of each crop were included to estimate the range in competitive ability within each crop. Crop and ryegrass biomass were recorded at anthesis and maturity.

Oat, triticale and canola were the most competitive crops, while field pea and lupin were the weakest competitors. Wheat and barley were intermediate depending on cultivar. For example, the dry weight of ryegrass measured at anthesis was 53-74 g/m^2 with oat, 70-71 g/m^2 with triticale, 88-104 g/m^2 with canola, 60-170 g/m^2 with barley, 81-201 g/m^2 with wheat, 237-284 g/m^2 with field pea and 304-377 g/m^2 with lupin, in each case depending on cultivar.

Large differences in competitive ability of crops and cultivars of wheat and barley show potential for greater suppression of weeds with more competitive crops. Further experiments are examining the reasons for the superior competitive ability of certain crops and cultivars.

PORPHYRIN INTERMEDIATES INVOLVED IN HERBICIDAL ACTION OF δ-AMINOLEVULINIC ACID IN *LEMNA PAUCICOSTATA* HEGELM

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Although δ-aminolevulinic acid (ALA) is a common precursor for the synthesis of chlorophylls and hemes, exogenously applied ALA causes photobleaching on the susceptible plants. It is generally accepted that the accumulated porphyrin intermediates act as photosensitizer for the production of singlet oxygen to destroy plant pigments and membrane lipids. However, the porphyrin species responsible for the action is still unclear. In this study, the relationship between porphyrins accumulation and appearance of phytotoxic symptom in an aquatic higher plant *Lemna paucicostata*, which is quite sensitive to ALA, is investigated.

When the plant was treated with ALA in darkness for 12 h and then exposed to light, electrolyte leakage occurred immediately. A chlorophyll content reduction of approximately 40% was caused by 1 mM ALA. Profiles of four porphyrin intermediates were determined during dark incubation and following light exposure.

ACIAR PROJECT FOR THE BIOLOGICAL CONTROL OF SIAM WEED IN INDONESIA AND THE PHILIPPINES

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Siam weed, *Chromolaena odorata*, is a major weed of pastures and plantation crops in West Africa and south-east Asia. Many potential biocontrol agents exist but only 2 have been trialled, without success to date. Siam weed continues to spread south, and is now in Papua New Guinea as well as Timor and Irian Jaya, and is threatening Australia. ACIAR is funding a 3-year project in which suitable insects will be sent from South America for detailed host-testing in quarantine in Indonesia and the Philippines, followed by field release if the insects prove safe. The project started in January 1993 and a stem-galling fly *Procecidochares connexa* is already being tested in quarantine in Indonesia and will be sent to the Philippines shortly. Other insects will be trialled next year.

PUBLIC ISSUES IN THE RELEASE OF HERBICIDE RESISTANT CROPS

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This paper outlines issues of public concern emerging in response to the breeding of herbicide resistant plants, including the release of transgenic plants, the potential for the transfer of the herbicide resistance gene to weeds, the increased selection pressure for the development of herbicide resistance in weeds, the potential for increased use of herbicides, and the potential impact of herbicides on the environment, specifically the accumulation in soil and the contamination of ground and surface water.

These are important issues in the context of Government initiatives in the development of sustainable systems of agriculture and pose an enormous challenge for stakeholders, including the agrochemical and seed industries, farmers, environmental and consumer interests. The Bureau of Resource Sciences is preparing a discussion paper on the subject in the expectation that Governments may be forced to intervene in order to balance the demands of competing interests.

SYNERGISM BETWEEN TWO FUNGI KILLS NOOGOORA BURR

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Biological control of the Noogoora burr *(Xanthium occidentale)* complex with fungi represents a possible alternative or complementary strategy to traditional control measures. The microcyclic rust, *Puccinia xanthii* can severely affect the growth of the *Xanthium* weeds in some regions of Australia but rarely kills them. The relatively strict dependency on optimum climatic conditions for epidemics of *P. xanthii* on the Noogoora burr complex limits its capacity as a classical biocontrol agent.

Several facultative parasitic fungi infect and cause localized disease lesions via leaf and stem rust lesions on Noogoora burr. Among the fungi tested, *Colletotrichum orbiculare* was the only fungus able to grow beyond the stem rust lesions into the surrounding tissue, girdle the stem and consequently kill the plant tissue above. *C. orbiculare* did not cause disease on healthy plants nor on plants previously infected by *Alternaria zinniae*, a potential bioherbicide for the *Xanthium* weeds. The unique synergy between *P. xanthii* and *C. orbiculare* suggests that *P. xanthii* alters the physiology of the infected and neighbouring host cells and renders them highly susceptible to *C. orbiculare*.

The use of *C. orbiculare* on rust infected populations of Noogoora burr may have the potential to control this weed in the field more effectively. Further investigations of the *P. xanthii* - *C. orbiculare* interaction at the cellular and biochemical levels are necessary to elucidate the interaction mechanism. This knowledge could be useful in the development of an effective bioherbicide for the control of the Noogoora burr complex.

INTEGRATED SHRUB MANAGEMENT IN SEMI-ARID WOODLANDS: A PRELIMINARY EVALUATION OF SUB-LETHAL CHEMICAL DEFOLIANTS APPLIED TO YOUNG COPPICE REGROWTH

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A series of screening studies were undertaken during 1990-92 to evaluate the effectiveness of several potentially useful chemical defoliants when applied over a range of concentrations to seedlings of *Cassia nemophila* and different aged coppice regrowth of *Eremophila mitchellii* and *E. sturtii*. Initial results, in terms of leaf death, were extremely promising and provided striking evidence that some chemicals, especially glyphosate (Roundup) were capable of mimicking fire by killing young shrub foliage (no older than one season's regrowth), even at the most dilute concentration (1: 80). Timing of secondary chemical treatment is likely to be critical. Research based on repetitive treatments imposed by fire using artificial fuel suggests that 80% of shrubs receiving a second defoliation using chemicals applied in the autumn may fail to recover. Only *c.* 20-30% mortality may occur from secondary spring defoliation.

This paper reports on the results of initial screening experiments and describes collaborative research currently underway in western New South Wales and western Queensland examining the application technology required for treating extensive areas of shrub-infested rangelands.

CROP TOLERANCE TO RESIDUAL HERBICIDES IN CENTRAL QUEENSLAND

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Under Central Queensland environmental conditions, it is assumed that the herbicides atrazine and chlorsulfuron are not as residual and break down much faster than they do in cooler environs. Current registered plant-back intervals for these herbicides apply in Central Queensland even though the intervals are very conservative, and due to this, the potential use of atrazine and chlorsulfuron is yet to be fully realised in this region.

Sorghum, sunflower, wheat and chickpea have been evaluated for their tolerance to these herbicides in the Central Queensland environment. Safe plant-back intervals as low as 75 days for chlorsulfuron with the summer crops have been recorded over three seasons. Safe intervals of 180 days for both atrazine and chlorsulfuron in the winter crops have also been recorded over three years. All herbicide applications were made mid to late spring.

CARDAMINE FLEXUOSA: THE REAL NURSERY WEED

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The intention of this study was to challenge the view that a local nursery weed is the winter annual *Cardamine hirsuta*. It also looked at the germination behaviour of glasshouse-produced seed to test for viability and dormancy.

Seeds were collected in nurseries from Adelaide, Newcastle, Southport, Brisbane, Stanthorpe, Townsville and Darwin. They were stored dry at room temperature and germinated monthly. The seeds from glasshouse-raised plants (20, 24, 29 and 33°C) were also tested for dormancy and viability. Flowers were examined for numbers of stamens.

From all sites surveyed the weed proved to be the polyploid *Cardamine flexuosa*. Seed viability was less than 9 months. Dormancy occurred when plants were grown at 20°C but plants from warmer environments showed immediate germination.

Control strategies need to be reassessed especially in the knowledge that the weed is polyploid and is constantly germinating. Its short viability should prove to be an asset.

PREDICTING SULFONYLUREA DEGRADATION IN SOILS DEPENDS ON A VALID MEASURE OF PH IN THE SOIL SOLUTION

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Hydrolysis of the sulfonylureas, chlorsulfuron and triasulfuron, in aqueous solution is dependent on temperature and pH. We wanted to know if soil pH and temperature could be used to predict the degradation rate of sulfonylureas in soils. Our results, comparing sterilised and unsterilised soils, indicate that chemical hydrolysis is the main pathway for degradation in acidic to neutral Western Australian sandy soils. In soils at field capacity, up to 90% of the herbicide is adsorbed but the adsorbed fraction seems to be equally susceptible to degradation. We came to this conclusion since the rate of degradation was the same at 2, 5 and 10% water content. We developed a relationship to predict sulfonylurea half-life using temperature and pH as inputs, based on first order kinetics of hydrolysis in buffered water. This relationship successfully predicted the half-life in an acidic soil using the incubation temperature and bulk pH of the soil, but greatly overestimated the half-life of neutral soils. In these soils, the bulk soil pH, measured in a 10 mM $CaCl_2$ suspension, may underestimate the true proton activity adjacent to solid surfaces in the soil solution by a unit or more. When adjusted, the model more closely predicts the half life in these soils.

CONTROL OF HIMALAYAN HONEYSUCKLE *(LEYCESTERIA FORMOSA)*

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Himalayan honeysuckle *(Leycesteria formosa)* is a deciduous, multi-stemmed shrub of Asian origin, which is spreading into native forests in Victoria. A trial conducted in the Mt Buffalo National Park evaluated four herbicides for the control of the plant. Low volume sprays, with a hand-held applicator were made in January 1992 either to the foliage or to the basal 30 cm of the stems.

Fourteen months after application, a complete kill of Himalayan honeysuckle was given by basal sprays of triclopyr at 1 kg/100 L of diesel fuel, triclopyr at 2 kg/100 L of a 1:4 mix of 'Ulvapron' spray oil and water, triclopyr plus picloram at 1 kg plus 0.33 kg/100 L of a 1:4 mix of 'Ulvapron' and water, and glyphosate at 9 kg/100 L of water. Metsulfuron methyl at 0.18 kg/100 L of water and 0.06 kg/100 L of a 1:4 mix of 'Ulvapron' and water were less effective. Foliar sprays of triclopyr at 1.71 kg/100 L of water, triclopyr plus picloram at 1 kg plus 0.33 kg/100 L of water and glyphosate at 4 kg/100 L of water also gave complete kills. However basal sprays, which require less spray volume, are preferable because they are quicker to apply, more target specific and lower in cost.

MINING AND WEEDS

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Noxious weeds are generally considered to be problems associated with agriculture and conservation. Other areas whereby weeds may potentially become a problem should be investigated and addressed accordingly. Mining is certainly no exception.

In the Northern Territory of Australia there are many weeds such as hyptis *(Hyptis suaveolens)*, spinyhead sida *(Sida acuta)*, flannel weed *(Sida cordifolia)*, Paddy's lucerne *(Sida rhombifolia)*, snakeweeds *(Stachytarpheta* spp), mission grass *(Pennisetum polystachion)*, grader grass *(Themeda quadrivalvis)*, sicklepod *(Senna obtusifolia)*, coffee senna *(Senna occidentalis)*, rubberbush *(Calotropis procera)*, and mimosa *(Mimosa pigra)* that quickly become established at and around mine sites.

Disturbance at mine sites predisposes the area to invasion by weeds. These weeds are spread between mines and throughout mine sites by the movement of trucks and machinery from infested to clean areas. Contaminated seed used in revegetation work may also introduce new weed seeds to remote areas.

Mining companies are becoming aware of the need to control weeds. Environmental Impact Statements, which are produced to support mining applications, now usually address weeds as an issue in the mine's management, and resources are being devoted to their control.

THE ECOLOGY OF *MYRSIPHYLLUM ASPARAGOIDES*, AN ENVIRONMENTAL WEED IN SOUTH-EASTERN AUSTRALIA

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Bridal Creeper (*Myrsiphyllum asparagoides*), a geophyte native to South Africa, is an invasive weed in both disturbed and undisturbed vegetation of southern Australia. In conjunction with a search for biological control agents in South Africa, its population biology at Point Nepean National Park in Victoria has been studied since 1992.

Shoots of bridal creeper begin emerging in late summer or autumn, depending upon rainfall, and nearly all senesce the following summer. Early emergents contribute most to the above-ground biomass of the plant. Maximum stem density occurs in August, averaging 91 stems m^2, when canopy cover averaged 75%. Tuber masses usually entwine to form dense mats just below the soil surface and comprise at least 94% of the plant's biomass. Tuber production begins in May and continues through winter. Birds disperse the fleshy fruits of bridal creeper; 46% of fruits are taken over summer. Seed germination in the field is affected by depth of burial; 54% of buried seed germinate after 3 months while only 2% of surface seed germinate.

Bridal creeper is a serious environmental weed. It is able to regenerate vegetatively from extensive tuber reserves and establish from seed (which may be dispersed to new sites) to reach high densities and cover. Its establishment may limit seedling regeneration of native species, alter soil and litter biota, and affect rates of litter decomposition and nutrient cycling. For effective biological control, defoliating agents, tuber-depleting organisms, and pre-dispersal seed predators will be required.

POTENTIAL MOVEMENT OF GLYPHOSATE AND METSULFURON METHYL RESIDUES IN COASTAL SAND DUNES

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The herbicides Roundup® (glyphosate) and Brush-Off® (metsulfuron methyl) have been applied to test sites on coastal sand dunes in the Jervis Bay National Park since 1985 to control bitou bush (*Chrysanthymoides monilifera* subspecies *rotundata)*. The experiments have shown that aerial applications of 1-2 L of Roundup® per hectare or 15-30 g of Brush-Off® per hectare are effective but test sites at Berwherre Beach were also treated by high pressure hand spraying at concentrations of up to ten times those applied from the air. There is concern that residues may leach towards the water table in permeable dunes.

We describe work in progress on a pilot scale to characterise and model seasonal variations in soil moisture at the test sites. Neutron probe measurements between November 1992 and March 1993 show that the profile from 10-150 cm depth has become uniformly drier, reflecting the generally uniform lithology of the dunes. Thin peat and clay layers at one site increase moisture retention. The rapid infiltration of water from a single rainstorm on 12 March 1993 has been followed with the probe.

The next phase of the study will incorporate modelling of the observed moisture profiles with the SWIM package. The soil profile will be sampled at the sites for the concentration of adsorbed herbicide and the risk of leaching in coastal dune systems assessed with SWIM and simple, one-dimensional transport models as an integral part of bitou bush control.

DISTRIBUTION OF BRIDAL CREEPER *(MYRSIPHYLLUM ASPARAGOIDES)* IN WESTERN AUSTRALIA

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Bridal Creeper (*Myrsiphyllum asparagoides*) is an environmental weed of significance in south-western Australia. The weed is spreading rapidly through important bushland of high conservation value on roadsides, farmland and public reserves. Surveys were started in 1990 to establish the extent of infestation. The plant is widespread and was found by the first author at over 90 localities, spread throughout the middle and lower south west. The Department of Conservation and Land Management has recorded bridal creeper for most coastal National Parks in south-western WA, from Yanchep, north of Perth to Israelite Bay east of Esperance. Historical records and current infestations are often isolated indicating colonisation of comparatively recent origin. Plant populations are often centred on towns indicating that humans are a major source of initial spread. Birds are considered important in spreading bridal creeper to isolated conservation areas. Control options being considered for bridal creeper include herbicide treatments and the introduction of biological control agents. The weed is being consdiered for proclamation as a noxious weed in south western WA.

OCCURRENCE OF THE RUST FUNGUS *UROMYCES RUMICIS*, A BIOLOGICAL CONTROL AGENT OF FIDDLE DOCK *(RUMEX PULCHER)* IN WESTERN AUSTRALIA

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The rust fungus *Uromyces rumicis* was first reported in Western Australia in 1986 from Perth. In its native habitat, Europe and Africa, the fungus is associated with *Rumex* and *Emex* species. The fungus is considered a potential biological control agent for these weeds in Australia. A survey of fungi on plants of Polygonaceae in 1990-1992 found *Uromyces rumicis* to be widespread in the wetter parts of south-west WA, but only *Rumex pulcher* (fiddle dock) was attacked. The fungus was absent on other *Rumex* species even when growing mixed with infested plants. Uredia and telia were only evident from the end of spring until plants senesced (November-January). At this time the dock plants have maturing seeds. It is likely that fungal development is too late to have a major impact on plant populations. The short period when spores are present explains why the fungus has been overlooked in the past. The observations in WA suggest that the climatic conditions suitable for other strains of the fungus would need to be considered if they are to be used as biological control agents against *Rumex* and *Emex* species.

A CANADIAN STRAIN OF *COLLETOTRICHUM GLOEOSPORIOIDES*, A POSSIBLE MYCOHERBICIDE FOR ST JOHN'S WORT, *HYPERICUM PERFORATUM*

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Two isolates of the fungus, *Colletotrichum gloeosporioides* (St John's Wort, Nova Scotia), were recently introduced from Canada into high security quarantine at the Keith Turnbull Research Institute.

The three strains of St John's Wort recognised in Australia, i.e. broad-leaved, narrow-leaved and intermediate-leaved forms were tested against the strains of *C. gloeosporioides*, as were plants collected from several infestations in Victoria and New South Wales. These tests indicated that Australian St John's Wort plants were susceptible to these strains of *C. gloeosporioides*. Preliminary host specificity tests were carried out on St Peter's Wort, *Hypericum tetrapterum*, and the Australian native *Hypericum gramineum*. It may be possible to develop *C. gloeosporioides* as a mycoherbicide as a later date, after further host-specificity testing.

THE BUSHWEED DATABASE OF ENVIRONMENTAL WEEDS IN AUSTRALIA

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The BUSHWEED database has been developed both to provide an overview of the environmental weeds of Australia and as a possible model for a global database of such weeds.

The database covers the scientific and common names of about 700 weeds, as well as the family, legislative status (if any), a brief outline of its biology, distribution by regions in each state and territory, distribution by natural and seminatural ecosystems invaded, and outlines of the known managerial, biological, physical and chemical methods of control appropriate to each weed in such systems, with references.

The database has been developed using the First Choice word processing packages, selected for its increased database capacity. It is being continuously updated and expanded as more information becomes available, and is available in hard copy as illustrated.

THE GLOBAL WORKING GROUP ON WEEDS OF CONSERVATION AREAS

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The Working Group on Weeds of Conservation Areas is an informal group of people involved with all aspects of the biology, ecology and control of the weeds that invade natural and seminatural ecosystems reserved for their conservation value, such as National Parks, throughout the world.

Formed during 1992, the group has fifty members in most continents. Its main objective is to put members in touch with each other through the address list, to circulate papers and other information that may have broad interest among members, and to encourage meetings as adjuncts to national, regional or world weed conferences. It may also work towards the development of a global database of the weeds of conservation areas.

THE INTERNATIONAL WEED SCIENCE SOCIETY

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The purpose of the IWSS is to encourage, promote and assist development of weed science and weed control technology on a global basis. The objectives are: to encourage and assist development of national and regional weed science societies; to promote and assist meetings, conferences and symposia on topics of international interest, to promote exchange and participation among individual members and weed science organisations; to develop a directory of weed science personnel and projects, and to publish a calendar of important events in weed science; to encourage excellence, high standards and creativity in weed science and technology research, to maintain liaison with relevant national and international organisations for the purpose of identifying, monitoring and solving new weed problems; and to promote, encourage and assist education and training in weed science and technology. The First International Weed Control Congress was held in Melbourne, Australia in February 1992 under the auspices of IWSS. Over 500 delegates from 46 countries attended. The Second IWCC will be held in Copenhagen, Denmark in 1996. Two newsletters and a membership directory are published annually. The current executive is President, Leon Smith (Australia); Vice President, John Terry (UK); Secretary-Treasurer, Raj Prasad (Canada); and Executive Secretary, Susan Larson (USA).

BIOLOGY, ECOLOGY AND CONTROL OF CATS-CLAW CREEPER

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Botanical, biological and ecological aspects of cat's claw creeper *(Macfadyena unguis-cati)* were studied in Redwood Park, Toowoomba, with chemical control trials being established in the same location. The propensity of the vine to establish itself in native bushland and proliferate using a range of ecological adaptions, is discussed along with the impracticality of physical control alone.

Trials investigated the efficacy of the four herbicides clopyralid, triclopyr, glyphosate and metsulfuron-methyl in the control of stolons, vines and seedlings over a thirteen month period. The best results were achieved by spraying freshly-cut vines on trees and stolons with 2.8% glyphosate or 1.2% triclopyr, and spraying seedlings with glyphosate or triclopyr at the same rates or 0.9% clopyralid.

FLUROXYPYR GIVES RAPID KNOCKDOWN OF MADIERA VINE (*ANREDERA CORDIFOLIA*) AND KILL OF MOTHER-OF-MILLIONS (*KALANCHOE* SPP.)

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Foliar application of 1.2% fluroxypr (4 mL Starane per litre of water without additional wetter) as a low pressure high volume spray gave rapid knockdown of the serious environmental weed Madiera vine *(Anredera cordifolia)* and quickly killed at least three species of the less serious Mother-of-millions (*Kalanchoe* spp.), with safety to kangaroo grass *(Themeda triandra)*.

Madiera vine carpeting the ground was treated during and just after flowering to wet both leaves and visible stems. Chlorosis and wilting occurred within two weeks, followed by progressive defoliation and collapse of stems. Long term control of a single application was unsuccessful, since regrowth occurred from tubers in the ground.

Mother-of-millions *(K. tubiflora)* treated at all stages before flowering by directed spraying from above and the side to wet stems and leaves wilted within one week, became chlorotic and began defoliating within two weeks, and collapsed within four weeks. Hybrid mother-of-millions *(K. tubiflorum x diagremontianum)* and live leaf *(K. pinnata)* reacted more slowly, but both were dead within six weeks.

ENVIRONMENTAL FACTORS INFLUENCE EFFICACY OF GLYPHOSATE APPLIED TO BARNYARD GRASS *(ECHINOCHLOA COLONA)*

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Glyphosate activity is affected by weather conditions before and after application and it is generally agreed that environmental conditions that promote growth will increase efficacy. The objective of this series of glasshouse experiments was to examine the efficacy of glyphosate against *Avena fatua*, a winter weed of south east Queensland, grown under different soil moisture, light and temperature regimes.

Pre-germinated seeds were grown under uniform conditions until they were 15 days old and then kept in either wet (-0.1 MPa, field capacity) or dry (-1.3 MPa, visible plant wilting) soil conditions for 3 weeks before glyphosate (180 to 360 g ha^{-1}) was applied. Light intensity did not influence the time it took the plants to die but visual damage was faster under full sunlight than 50% shading (*ca.* 500 µmol m^{-2} s^{-1}). Moisture stress reduced the level of glyphosate control, reduced physical damage and delayed mortality being the most obvious changes. The effect of glyphosate was similar on a number of different biotypes when no moisture stress was applied, however under moisture stress, the time it took plants to die varied suggesting biotype differences. Temperature also influenced efficacy, and level of control was dependent on an interaction of soil moisture level with temperature. Better control was possible on plants growing under well watered conditions at low temperatures (20°C) compared to plants growing under moisture stress at high temperatures (30°C).

Soil moisture level and air temperature and to a lesser extent biotype and light intensity all have an important influence on the glyphosate efficiency of wild oat, soil moisture level being the most important factor.

ENVIRONMENTAL FACTORS INFLUENCE EFFICACY OF GLYPHOSATE APPLIED TO WILD OAT *(AVENA FATUA)*

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Glyphosate activity is affected by weather conditions before and after application and it is generally agreed that environmental conditions that promote growth will increase efficacy. The objective of this series of glasshouse experiments was to examine the efficacy of glyphosate against *Echinochloa colona*, a summer weed of south east Queensland, grown under different soil moisture, light and temperature regimes.

Pre-germinated seeds were grown under uniform conditions until they were 10 days old and then kept in either wet (-0.1 MPa, field capacity) or dry (-1.3 MPa, visible plant wilting) soil conditions for 3 weeks before glyphosate (180 to 360 g ha^{-1}) was applied. Light intensity did not influence the time it took the plants to die but visual damage was faster under full sunlight than 50% shading (*ca.* 500 µmol m^{-2} s^{-1}). Moisture stress reduced the level of glyphosate control, reduced physical damage and delayed mortality being the most obvious changes. Temperature also influenced efficacy, and level of control was dependent on an interaction of soil moisture level with temperature. Better control was possible on plants growing under well watered conditions at low temperatures (20°C) compared to plants growing under moisture stress at high temperatures (35°C).

Soil moisture level and air temperature and to a lesser extent light intensity all have an important influence on the glyphosate efficiency on barnyard grass with soil moisture level being the most important factor.

RUBBER VINE RUST, *MARAVALIA CRYPTOSTEGIAE*, A POTENTIAL BIOCONTROL AGENT FOR RUBBER VINE, *CRYPTOSTEGIA GRANDIFLORA*

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The rust fungus *Maravalia cryptostegiae*, from Madagascar is seen as the single most damaging parasite of rubber vine *(Cryptostegia grandiflora)*, a serious weed of rangeland and native plant communities in northern and central Queensland.

Studies of the rust's taxonomy, biology and host specificity were carried out in the United Kingdom from 1985 to 1992 to determine its suitability as a biocontrol agent. The results of this work clearly confirm that it is suitable.

These results together with a recommendation that the rust be imported and released in the field in Australia were lodged with the Australian Quarantine and Inspection Service in mid-1992. Subsequent to approval being granted, the rust was released in the field in late summer 1993. Various aspects of the project are illustrated.

ACETOLACTATE SYNTHASE ACTIVITIES AND AMINO ACID LEVELS IN BENSULFURON METHYL RESISTANT PLANT CELLS

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Selection of cultured plant cells resistant to bensulfuron methyl (BSM) and BSM effects on acetolactate synthase (ALS) activity and amino acid level were investigated to clarify their resistance mechanism.

BSM severely inhibited growth and ALS activity of suspension cultured rice and carrot cells. Rice and carrot cells resistant to 1-10 µM and 10 µM BSM, respectively, were stepwise selected after culturing in the media containing the herbicide. These resistances were kept stable for more than a year in BSM-free media. During and even after selection, ALS from these resistant cells became far less sensitive to the herbicide and was over 1000 and 60 times less inhibited than in susceptible cells, respectively. Levels of branched-chain amino acids in the resistant cells were considerably higher than in susceptible cells. BSM greatly affected amino acid levels, especially decreasing branched-chain amino acids and soluble protein levels, while BSM had little effect in the resistant cells.

These results might be due to the development of ALS being insensitive to BSM, or less sensitive to feedback inhibition as well, which may be involved in the resistance mechanism.

EFFECT OF AERIAL WATER VOLUME ON TRICLOPYR/PICLORAM APPLIED TO RUBBER VINE *(CRYPTOSTEGIA GRANDIFLORA)*

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Rubber vine mortality with triclopyr/picloram (Grazon DS) + 2 mL organosilicone (Pulse)/L spray volume was evaluated to determine the optimum carrier water volume for aerial application using a jet ranger helicopter. Low volume sprays (100-150 L/ha) generally used for woody weed control, achieve excellent brown out but can result in poor plant mortality. Applying triclopyr/picloram at the registered aerial rate of 900 g triclopyr/300 g picloram/ha and varying the spray volume applied of 50, 100, 200 and 400 L/ha killed 30, 54, 68 and 98% of the treated plants respectively. Rubber vine control was similar (approximately 95% mortality) when the herbicide was applied at 900/300 g/ha with a spray volume of 400 L/ha and 4800/1600 g/ha with a spray volume of 200 L/ha. Initial trials indicate that aerial spray volume influences rubber vine mortality. Further research to find the optional aerial water volume to maximise herbicide efficacy would minimise the cost for effective woody weed control.

PASTURE MANIPULATION WITH SIMAZINE, PARAQUAT AND DIQUAT

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Two experiments conducted during 1991 and 1992 in Jerramungup WA, demonstrated that combinations of simazine with either Sprayseed® (75 g/L diquat plus 125 g/L paraquat) or Gramoxone®) (200 g/L paraquat) are effective for the control of grass (*Lolium rigidum* and *Vulpia* spp.) and broad-leaved (*Erodium* spp.) weeds in pastures with little damage occurring to companion subterranean clover (*Trifolium subterraneum*).

A range of rates and combinations of the three herbicides were investigated. Simazine applied at 250 g/ha with 500 to 750 mL/ha of Gramoxone or Sprayseed was the optimal treatment for least cost (approximately $6.00/ha). When applied alone the range of species controlled by each herbicide was reduced compared to that controlled by the mixed herbicide application. There did not appear to be an influence of time of herbicide application (2 June compared to 24 June 1992) on control of *Vulpia* spp. Delaying application time improved control of *L. rigidum* and *Erodium* spp.

These chemical combinations provide control of a range of weed species and result in limited damage to subterranean clover. Application of these herbicide mixes will greatly reduce pasture density and the presence of evenly distributed subterranean clover seedlings is essential. Time of herbicide application will depend on livestock feed availability, weed growth and the importance of a cereal disease break for a following cereal crop.

A STUDY OF THE MODE OF ACTION OF THE HERBICIDE BUTACHLOR

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Butachlor (*N*-(buthoxymethyl)-2-chloro-*N*-(2,6-diethylphenyl)acetamide) is one of the most popular herbicides used for the control of weeds in paddy fields in Taiwan. However, the biochemical aspects of the action of butachlor have been rarely studied.

The primary site of action of butachlor was studied in time course (0.5-8 hour) and concentration (0-70 μM) experiments to determine the effect of butachlor on lipid, protein and RNA synthesis in leaf cells from chlorella *(C. pyrenoidosa)* and of tobacco (*Nicotiana tabacum* cv. Wisconsin 38) (representing sensitive types for butachlor), and embryo cells from rice (*Oryza sativa* cv. Tainan 5) (resistant type). Appropriate amount of ^{14}C precursors were used for each process during incubation for 8 hours.

The results indicated that the primary site of action of butachlor in plants might be on protein synthesis. The results also demonstrated that the inhibition caused by butachlor was not significantly different between sensitive and resistant type plant cells.

PICLORAM/TRICLOPYR BASAL BARK SPRAY FOR CONTROL OF WOODY WEED REGROWTH

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Extensive trials in Australia have shown that a picloram/triclopyr ester formulation, applied in diesel as a basal bark spray to a stem height of 30-50 cm above ground level, has controlled a wide range of woody weed regrowth. Species controlled include rubbervine *Cryptostegia grandiflora*, parkinsonia *Parkinsonia aculeata*, Chinee apple *Ziziphus mauritiana*, lantana *Lantana camara*, *Acacia* spp. *Eucalyptus* spp., *Lophostemon* spp., *Angophora subvelutina*, *Melaleuca* spp., *Eremophila* spp., camphor laurel *Cinnamomum camphora*, a tree pear *Opuntia* sp., mesquite *Prosopis pallida* syn. *limensis*, wilga *Geijera parviflora*, goundsel bush *Baccharis halimifolia*, heartleaf poison bush *Gastrolobium grandiflorum*, sweet briar *Rosa rubiginosa*, hawthorn *Crataegus laevigata*, narrowleaf hopbush *Dodonea attenuata**, Australian blackthorn *Bursaria spinosa*, yellow teatree *Leptospermum flavescens*, guava *Psidium guajava**, tree of heaven *Ailanthus altissima*, hard milkwood *Alstonia muellerana*, desert cassia *Cassia nemophila**, Ellangowan poison bush *Myoporum deserti**, needlewood *Hakea sericea*, turpentine *Syncarpia glomulifera* and red ash *Alphitonia excelsa*.

Results have shown that 2 g acid equivalent picloram + 4 g ae triclopyr/L of diesel (formulation diluted 1:60) has consistently given a high level of control over variable seasonal conditions on regrowth with stem diameters to 10 cm at ground level. Cut stump application is also effective on similar and larger plants. Picloram/triclopyr basal bark application is an effective replacement for 2 g ae picloram + 8 g ae 2,4,5-T/L of diesel, which had a wide acceptance for 18 years before it became commerically unavailable in the mid 1980's.

* Sprayed with 4 gae picloram + 8 gae triclopyr/L diesel in trials to date.

THE ALAN FLETCHER RESEARCH STATION - QUEENSLAND'S MAJOR WEED CONTROL LABORATORY

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The Alan Fletcher Research Station (AFRS) was established by Queensland Department of Lands (DOL) on the site of the Commonwealth Prickly Pear Board laboratory in Brisbane. The AFRS continues surveillance of pest cacti, but its role broadened. The AFRS is part of the Research Section of DOL Land Protection Branch, with responsibility for research directed towards minimising the economic, environmental and social impact of noxious plants and animals. The thirty staff include: five entomologists, a plant pathologist and nine assistant scientific officers involved in biological control; two agronomists, a chemist and three assistant scientific officers involved in mechanical and chemical control of weeds; and a zoologist involved in control of animal pests. Facilities include a building housing offices and laboratories, five glasshouses, and a large quarantine glasshouse.

FLESHY FRUITED WEEDS AND NATIVE SPECIES IN THE DIET OF NATIVE AND INTRODUCED BIRDS

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The process and impact of weed invasion in a forest remnant was studied near Nelson, New Zealand. The forest canopy was dominated by totara *(Podocarpus hallii)* and beech *(Nothofagus solandri)* with a mixed understorey including many fruiting shrubs. Himalayan honeysuckle *(Leycesteria formosa)*, barberry *(Berberis glaucocarpa)*, and hawthorn *(Crataegus monogyna)*, are the main weeds in the understorey and on the forest margins. The diet of native and introduced birds was determined from droppings collected from mist netted birds. The native bellbirds eat only the fruit of native plants, tuis eat mostly native fruits and a small amount of Himalayan honeysuckle, while waxeyes eat a wide range of fruit including some Himalayan honeysuckle and barberry. Introduced blackbirds eat some native species but their fruit diet is dominated by Himalayan honeysuckle, barberry, and hawthorn.

Blackbirds, and to a lesser extent waxeyes, are probably the main dispersers of fleshy fruited woody weeds in forest remnants. There may also be a feed-back mechanism involved with these birds bringing in weeds which in turn attract introduced birds and more weeds. The establishment of fleshy fruited weeds at the expense of native shrubs creates an inferior habitat for native birds, particularly bellbirds. In the interests of native bird habitat, control of these weeds is therefore warranted where they are likely to be replaced by native shrubs.

BIOLOGICAL CONTROL OF WATER HYACINTH IN AUSTRALIA, THAILAND AND MALAYSIA

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Working Group on Biological Control of Aquatic Weeds, Malaysia
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As part of a 1990-1993 collaborative project, the biological control agent *Neochetina bruchi* Hustache (Coleoptera: Curculionidae) was introduced to Australia, Thailand and Malaysia to supplement the effects of other agents already present. Initial stocks were obtained from USDA Florida. Rearing and host specificity testing of *N. bruchi* began at CSIRO's Long Pocket Laboratories, with the first Australian releases made in December 1990. Rearing of was also undertaken by the NSW Agriculture Research and Advisory Station, Grafton for releases in NSW, and by the Charters Towers Tropical Weeds Research Centre, Lands Protection Branch for releases in northern Queensland. CSIRO supplied starter colonies of *N. bruchi* to both Thailand and Malaysia. In Thailand, the National Biological Control Research Center (NBCRC), Bangkok host-tested *N. bruchi* and began releases in April 1991. At ASEAN-PLANTI laboratories in Malaysia, the Working Group on Biological Control of Aquatic Weeds also host-tested *N. bruchi* and began releasing in peninsula Malaysia in May 1992. The agent is now established in all three countries, however it is still to early for a measurable impact on the weed. The project is an excellent example of collaboration at state, national and international levels and has resulted in cost-effective, widespread release of a potentially valuable biological control agent. Other benefits included a high degree of scientific interaction and training which benefited all three countries. The project was supported by the Australian Centre for International Agricultural Research (ACIAR).

THE DEVELOPMENT OF A TASMANIAN HERBICIDE ADVISORY PACKAGE

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A data base using D-Base IV (R) contains crop and non-crop herbicides and their weed susceptibilities for Tasmania. A user friendly expert system was developed to integrate the data base and provide the latest herbicide information quickly based on weed, crop or non-crop situation. The package will soon be placed on the DPIF computer network and will be commercially available to other government departments and agri-business in the state. The package could be modified for use outside Tasmania.

A COMPUTER EXPERT SYSTEM FOR OPTIMUM SELECTION OF HERBICIDES FOR USE IN SUGARCANE

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A computer expert system has been developed to aid extension personnel and cane growers in the selection of appropriate herbicides for use in sugarcane.

The result is a program based on LPA Prolog which is easy to use, and presents registered recommendations for the control of common weeds ranked by efficacy and cost. There are six regional variations of the program to cater for local herbicide usage and local weed species.

A COMPUTER-BASED SYSTEM FOR PREDICTING THE POTENTIAL DISTRIBUTION AND RELATIVE ABUNDANCE OF SPECIES IN RELATION TO CLIMATE

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CLIMEX is a dynamic simulation model which enables the estimation of an animal or plant's geographic distribution and relative abundance as determined by climate. CLIMEX is applied to different species by selecting the values of a series of parameters which describe the species' response to temperature and moisture. A population "Growth Index" (GI) describes the potential for growth of a population during the favourable season and four Stress Indices (Cold, Hot, Wet and Dry) describe the probability of the population surviving through the unfavourable season. The GI and Stress Indices are combined into an "Ecoclimatic Index" (EI), to give an overall measure of favourableness of the location or year for permanent occupation by the target species. The results are presented as tables, graphs or maps.

A species' climatic requirements are inferred from its known geographical distribution, relative abundance and seasonal phenology. Some life cycle data, such as developmental threshold temperatures, can be used to fine tune or interpret the CLIMEX parameter values. Once parameter values have been estimated, CLIMEX can be used to make predictions for independent locations.

DEVELOPMENT OF A COMPUTER AIDED CHEMICAL WEED CONTROL EXPERT SYSTEM

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A computer aided expert system is described which helps weed scientists and farmers in making ecologically and economically correct chemical weed control decisions.

The program enables the input and modification of data; enquiries by common and scientific names of weed/s and crop/s and by herbicide/s; the making of herbicidal control decisions with and without identification by morphological characters; development of experimental design and analysis; and the establishment of mathematical models by means of curve simulations.

Program testing has given satisfactory results.

WOODY WEED CONTROL BURNS

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Fire has been recognised as an effective and economic management tool against encroachment of woody weeds in semi-arid areas. Research and trial burns conducted by NSW Agriculture, CSIRO and NSW Department of Conservation and Land Management (CaLM) have identified the conditions suitable for a control burn, and a strategy for implementation.

A video for the instruction of personnel involved in conducting a control burn has been produced by the Woody Weeds Taskforce. The taskforce includes landholders and staff of NSW Agriculture and CaLM. The video demonstrates the procedures that should be followed to ensure safety of people and property, and to achieve a successful burn in a designated area.

Control burns should take place in the context of a whole property plan, integrating the needs of stock and pasture. The video discusses the conditions suitable for burning in terms of fuel, shrub species, climatic conditions and time of year. It states clear guidelines for the preparation of firebreaks, backburns and lighting of the headfire. The importance of adequate personnel, equipment and machinery for fire control is emphasised.

The video will be useful as a training aid for all Departments and landholders planning to use management burns.

THE ECOLOGICAL IMPACT AND CONTROL OF BLUE THUNBERGIA *(THUNBERGIA GRANDIFLORA)*

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This video demonstrates the devastating ecological impact of Blue Thunbergia *(Thunbergia grandiflora)* on rainforests in World Heritage Areas of the wet tropics in Queensland.

After 26 herbicides were screened in the field, only the herbicide imazapyr achieved successful control. Imazapyr is now registered for the control of Blue Thunbergia at 1:133 (1.88 g/L). Commercial applications have proven highly successful in the control and clean up of Blue Thunbergia infestations.