REVIEW OF WEED CONTROL IN AUSTRALIAN FORESTRY: PRACTICE AND PRIORITIES

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Summary. Weed control practice in forestry has been influenced by the increasing use of grasslands and second rotation sites for plantation establishment, the loss of 2,4,5-T as a reliable and cheap chemical for woody weed control, and greater public concerns about the effects of chemicals on human health and the environment. Current methods and trends are briefly reviewed, and research priorities are suggested. These include: greater emphasis on economic analysis; environmental effects of herbicide application; and more applied research on techniques for establishing native trees on grasslands. The forestry market is small, and is not well supported by the chemical companies. Weed research has suffered as a result from a pressing need for applied work to support management. In some areas a more basic approach is required, for example, in the elucidation of factors affecting pine response to triazine herbicides.

INTRODUCTION

Woody weeds have always been recognised as a critical factor affecting forest productivity, and the most significant developments in forest weed control in the past have involved the substitution of mechanical and chemical methods of woody weed control for labour-intensive manual methods. In the last ten years the pace of change in forestry weed control has accelerated. Restrictions on the use of the cheap and reliable chemical 2,4,5-T has necessitated much applied research on alternative chemicals for woody weed control. The increased cost of the alternatives has led to radical changes in the economics of many operations and has encouraged innovation in chemical application techniques. Concerns about environmental pollution and worker health have severely constrained some formerly acceptable operations and have increased costs. Woody weeds have become less important as purchased grasslands and second rotation sites have become an increasing proportion of the land used for plantations. There has been a greater appreciation of the impact of weed competition on plantation productivity, and this appreciation, together with environmental and health concerns and increasing costs, have encouraged foresters to become more expert in weed control technology.

More recently, community and government interest in tree planting on degraded industrial and agricultural land has introduced foresters to a new tree and weed environment.

This paper will discuss the status of weeds in Australian forestry, the changes that are occurring in weed control practice, and priorities for research.

WEED CONTROL IN NATURAL FORESTS

Silvicultural treatments. In those natural forests which are allowed to regenerate naturally after harvest, low productivity and the extensive nature of management generally preclude any special weed control operations in the regeneration period. However, regeneration practices such as burning or mechanical seedbed disturbance are often designed to favour desirable tree species over competing "weeds".

Stand improvement practices such as cull removal and thinning can be regarded as a form of weed control. Manual felling or ringbarking are still used in these operations, often in conjunction with manually applied herbicides (basal bark, injection, or cut-stump). 2,4,5-T, either alone or in mixture with picloram, was formerly widely used for this purpose, and there has been considerable research directed at finding alternative chemicals. For stem injection, triclopyr (with or withour picloram), hexazinone and glyphosate seem to be acceptable, and MCPA and dicamba can also be used in some circumstances (11, 28, 29). Triclopyr and glyphosate also work well as cut-stump treatments (14, 29). These treatments are labour-intensive, but there seems little potential for increasing productivity.

Grazing as a means of weed control. While grazing has always been important in the vegetation management of forest, the deliberate use of goats to control weeds in native forests is a recent innovation. In cypress pine, *Callitris glauca*, forests in central N.S.W., feral goats are being used successfully to eliminate excess cypress pine regeneration and other woody weeds, to improve grazing values and to reduce fire hazard. Intensive and informed livestock management is necessary if this type of operation is to be successful and economic.

Roadside weed control. The most frequent weed control activity in natural forests is roadside spraying, which is carried out to maintain access and sightlines. Here the need is for treatments that will selectively remove woody species without creating unsightly and erosion-prone bare earth. This has traditionally involved the high volume application of 2,4,5-T, or 2,4-D through handguns. Triclopyr is a reasonable substitute for 2,4,5-T for most weeds, but fails to control lantana, *Lantana camara* (29), one of the main problems in wet coastal forests. While it controls lantana and other woody weeds, glyphosate is not always acceptable because it is not selective to desirable ground vegetation. The relatively high costs of the new herbicides, and new concerns about operator safety, has focussed attention on the antiquated and inefficient techniques often used for roadside spraying.

Noxious weeds in native forests. Noxious weeds are a special problem in native forests, especially those that have been disturbed. Weeds such as blackberry, *Rubus fruticosus*, lantana, broom, *Sarothamnus scoparius*, privet, *Ligustrum* spp., pampas grass, *Cortaderia selloana*, and serrated tussock, *Nassella trichotoma*, can restrict access, increase fire risk, impair conservation values, as well as invading adjacent uninfested agricultural land. Poor access and the low economic productivity of many native forests makes the prospect of control of these weeds using conventional methods very poor, except in special high value situations, such as urban bushland.

Biological control is a possibility in some cases, and education, legislation and quarantine restrictions can delay the introduction and spread of some potentially serious weeds. For example, the forest services have been lobbying through the Australian Weeds Committee to restrict import of *Cortaderia jubata* (a pampas grass), which is a major forest weed in New Zealand. This species has however now been identified in Tasmania, having apparently entered as a contaminant in imported *C. selloana* seed.

WEED CONTROL IN PLANTATION FORESTS

Woody weeds. Most forest plantations in Australia in the past have been established on previously tree-covered land. The main weed problem has been with regenerating woody species, chiefly *Eucalyptus* and *Acacia*. These woody weeds can seriously reduce wood production (20), and any benefit resulting from nitrogen accretion to the soil from the leguminous *Acacia* weeds is far outweighed by their competitive effect (39). In a review of weed control practices in Australian radiata pine plantations carried out by Flinn and Fag (9), it was shown that in 1983 $3 m, or 62% of total weed control expenditure, was on woody weeds. The area treated was almost 40,000 ha. Techniques used included manual or mechanical slashing and ploughing, stem injection or cut-stump herbicide treatments, and ground or aerial broadcast applications of herbicides. Reasonable alternatives to 2,4,5-T have been found for most woody weeds in plantations; thus glyphosate and triclopyr are suitable for spot spraying (7, 14, 28) and broadcast aerial treatments of clopyralid or hexazinone can be used for selective removal of *Acacia* and other woody weeds (7, 10). Triclopyr, hexazinone and glyphosate are also useful for stem injection and cut-stump treatment of larger woody weeds in plantations (14, 26, 28).

The higher cost of the newer herbicides, and operator safety and environmental concerns, have led to interest in innovative application techniques, such as soil drenching with hexazinone and clopyralid (4, 6).

Another interesting innovation has been the use of herbaceous cover crops to inhibit woody weed regeneration in hoop pine plantations (34). Similarly, attempts to modify the weed flora in favour of less competitive or more easily controlled species have been made in radiata pine plantations in South Australia (2).

Plantation species vary in their tolerance to weed competition - in Queensland, Carribean pine, *Pinus caribaea* var. *hondurensis*, can tolerate higher woody weed densities than slash pine, *P. elliottii* (24). Extrapolation of results and conclusions between sites and species can therefore be misleading.

Blackberry and other noxious weeds. Blackberry is a major weed of establishing plantation forests in N.S.W. and Victoria, especially on old farmlands and second rotation sites. Blackberry is a declared noxious weed, and can suppress tree growth and prevent access for essential cultural and harvesting operation. Existing strains of the introduced blackberry rust are not persisting in the higher altitude plantation areas. While techniques and chemicals are available to control blackberry before planting, and in older stands where there is access, the chemicals that have replaced 2,4,5-T (triclopyr, glyphosate and metsulfuron) lack selectivity to the crop trees and cannot be sprayed unshielded. Forest services would welcome a chemical that could be sprayed over young pines to control blackberry.

Forestry can also inherit other noxious plants, including various species of thistles, St. Johns's wort, *Hypericum perforatum*, and serrated tussock, when acquiring framlands for plantations. Though complete eradication is sometimes attempted, natural processes of canopy closure, coupled with strategic boundary spraying, can often eliminate spread to adjacent agricultural lands.

Aerial application of herbicides to control woody weeds. Aerial application is an essential tool in forest weed control since it is insensitive to the access problems common in forests, and allows the treatment of large areas quickly and with minimum cost. Problems of inadequate control of woody weeds are often encountered in aerial treatments (38), but are almost always due to mistakes in application (32). Aerial pesticide application is an area of some public interest, mainly due to fears of long distance drift, environmental pollution and public health hazards. The high public profile, of the forest services can lead to serious problems when mistakes in aerial application are made - in Victoria the aerial application of herbicides in forests has been banned because of a single instance of long-distance herbicide drift.

The key to better weed control efficacy and reduced drift hazard in aerial applications is training and the use of appropriate techniques. While it is very expensive, the best way of achieving this is by acquisition of an in-house aerial spraying capability, and by intensive training of the personnel involved, as has been done by the N.S.W. Forestry Commission. This approach has been made possible by the use of an aircraft acquired primarily for firefighting purposes.

While work to date has suggested that the risk of pollution of streams from properly conducted aerial spraying operations is very small (26), it is important that data be gathered for other chemicals and sites so that the inevitable criticisms can be answered. This work should also be extended to monitor the environmental effects of ground application of herbicides.

Grassland establishment. One of the most important influences on forest weed control in recent years has been the increasing use of purchased grassland for new plantations. In the peiod 1980-85 the N.S.W. Forestry Commission purchased annually an average of 4,200 ha of substantially cleared farmland for a plantation program averaging 5,000 ha per year. Established pastures offer much more serious competition to newly planted trees than woody weeds. This is mainly due to the greater root intensity of pasture species in the topsoil (30). Recent work in South Australia and Victoria (31, 36) has emphasised the importance of moisture conservation and weed control in the early nutrition and growth of plantations. The competitive effect of pasture, and the responses to herbaceous weed control, decrease as the tree roots explore the subsoil (36). Initial early attempts to establish trees on grasslands without spcial site preparation mostly failed, and mechanical methods, such as ploughing, ripping and scalping are of limited value on improved pasture. The success of the current grassland planting programs is based on the use of selective, residual herbicide techniques developed in the 1970's (2). For radiata pine the most important herbicide for establishment in pasture is atrazine. In many areas this has been used at alow rate with amitrole (2), but the limited residual control offered by low rates of atrazine on acid soils, and the damage caused to pine by amitrole, led to the introduction of techniques using high rates of atrazine alone (*c.* 8 kg a.i. ha^{-1}) in N.S.W. in the late 1970's. At this rate atrazine is an effective knockdown herbicide on many annual and perennial pasture species. Hexazinone is also used in radiata pine plantations for pasture control, often in mixture with atrazine, but high cost and lack of selectivity has limited its acceptance. The control of vigorous perennial grasses, such as phalaris, paspalum and cocksfoot is still a problem, because these species are not adequately controlled by atrazine at selective rates. Preplanting mixtures of glyphosate plus atrazine (plus ammonium sulphate) seem to be effective in this situation and are cheaper than amitrole/atrazine or hexazinone/atrazine mixtures.

An interesting benefit of weed control in high altitude grasslands is the reduction in frost damage observed where bare earth is maintained around tree seedlings - this can increase minimum air temperatures by 2-3°C and significantly reduce frost damage (41). An additional benefit of bare earth on these cold sites is the incresed soil temperature, and associated better early root growth of the newly planted seedlings (17).

Despite claims about "stimulation" of radiata pine growth with atrazine (33, 37), the tolerance of this species to atrazine is definitely limited, and overdosing, with seedling death or suppression, is quite common. The response of pines to atrazine is related to soil conditions, especially pH, organic matter and moisture content, since these affect adsorption and persistence. Because of the importance of atrazine to plantation forestry in Australia, a priority should be basic research to elucidate the relationships between the soil properties and environmental conditions that affect atrazine availability and activity within the plant.

Second rotation weed control. As plantation schemes approach maturity second rotation planting is becoming more common. Plantations are invaded by a wide variety of herbaceous understory plants during their lifetime, with the result that herbaceous weeds have become a serious problem on many second rotation sites (2). Herbicide techniques that originated on pasture sites are being increasingly used on second rotation sites, though access problems have meant that special application methods are sometimes required. Thus aerial application is being increasingly used, and because of rough ground conditions ground-driven pumps on boom sprayers are needed to maintain accurate application rates. An additional problem on second rotation sites is that of unwanted pine regeneration. Small pine regeneration (<5 cm) is most satisfactorily controlled by high volume spraying with dicamba or diquat and/or paraquat (12, Hall, unpublished data), but larger seedlings are usually removed manually or mechanically. Application of atrazine at 8 kg ha^{-1} significantly reduced pine seedling germination in one trial on a second rotation site (Hall, unpublished data). The costs of manual of mechanical regeneration control, and the use of slash-mulching methods of site preparation, rather than the previous broadcast burning or windrowing techniques, is likely to mean that control of regeneration will continue to be a research priority.

Bracken. Bracken fern is a major weed on the sandy plantation soils in South Australia (2), and much local research has examined techniques for suppressing this species. Pre-planting applications of glyphosate seem to be the preferred method, though the new herbicide metsulfuron is also promising.

Eucalypt and amenity plantations. There is increasing public and political interest in tree establishment on farms and degraded industrial areas, such as mine sites, but in many of these areas there is intense competition from pasture weeds. There would be no problem if the techniques used for pines could be extrapolated to the native species, but while propazine is used in some eucalypt plantations, native species in general lack tolerance to the triazine group of herbicides (18).

Many community groups involved with tree planting also have ideological objections to the use of herbicides. The suggested alternatives include hand weeding and mulching, and while these may be suitable in small ares, they are generally impractical for large planting schemes. Mulching can also have severely detrimental effects on tree establishment on cold sites (17). Plastic tree shelters are becoming more popular, and allow spraying of non-selective chemicals around trees. However, the weed control achieved is only temporary, and ther are still unanswered questions about the effect of the high temperatures inside these shelters on tree establishment.

In trials carried out by the N.S.W. Forestry Commission oryzalin and diphenamid were identified as pre-emergence herbicides suitable for over-spraying planted seedlings of native species. These chemicals were chosen for testing because they act by inhibiting growth of newly germinating weed seedlings, and unlike the triazines, are not translocated to the leaves to inhibit photosynthesis. Tree tolernce is not dependent on an inherent physiological ability to detoxify the herbicides, or close control of application rates, as appears to be the case for the triazines. All species should therefore possess similar tolerance, and there is less potential for accidental overdosing. These herbicides have thus proved useful for weed control in plantations of poplars, which are susceptible to the triazine herbicides. Diphenamid may also be suitable for pre-emergence weed control where native trees are direct-seeded rather than transplanted. These herbicides will not however control established weeds, and some weed species are tolerant even to pre-emergence applications. New chemicals developed for control of grass weeds in broad-leaved crops, such as fluazifop, are also suitable for post-emergence weed control around trees (18), but have no effect on broad-leaved weeds. More work is needed to develop reliable methods of pre- and post-emergence weed control in these amenity plantations.

NURSERIES

For the species raised in containers (mainly natives), weed control in the nursery is not a major problem; most weeds can be eliminated by the use of sterile growing media, and wind and water borne weeds can be handled relatively easily and cheaply by hand, or with chemicals such as granular oxadiazon (23).

However, the important plantation species, which are mainly exotic conifers, are grown for reasons of economy in open beds, and weeds are commonly the biggest pest problem in such nurseries. Most of the crop species grow relatively slowly and rarely form a complete canopy; weeds enter with the wind, irrigation water and seed covers, and are encouraged by the high fertility and good water availability.

Tree nurseries are a high value crop; large amounts are invested in land purchase, clearing, road construction and site preparation in the expectation of having a supply of seedlings for the planting season, and thus a nursery failure can have serious and far-reaching consequences.

The result has been a conservative approach to nursery management, and a reluctance to take risks with new techniques, especially those involving the use of herbicides. For many years weed control relied on hand weeding, sanitation, and to some extent spraying with mineral spirits.

However, in the late 1960's and 1970's the increasing cost of labour, and the exhaustion of the soil in many of the small, continuously cropped plantation-based nurseries, led to the creation of large centralised nurseries. These had significant economies of scale, and allowed the introduction of mechanised techniques, efficient irrigation systems and rotational cropping. However, the use of traditional weeding techniques in these nurseries required impossibly large workforces.

Following successful trials in New Zealand (25, 40) and Australia (1), the pre-emergence herbicide mixture propazine + chlorthal was widely introduced

into open-root pine nurseries in the early to mid 1970's. This mixture can substantially reduce weeding costs (savings of $50,000 in the first year of introduction were recorded in one nursery in N.S.W.). The mixture is still the most satisfactory broad-spectrum herbicide treatment available for pre-emergence use in nurseries (15). Claims that the propazine component stimulated the fungal disease *Phytopthora cinnamomi*, in nursery soils (21) have not been substantiated in subsequent work.
In open root nurseries of eucalypts, linuron has been used in the same way as the propazine+chlorthal mixture (40).

While pre-emergence herbicides can greatly reduce weed problems they rarely eliminate them. Mistakes in pre-emergence timing or application technique, resistant weed species, weed seed dormancy, introduction of weed seeds in irrigation water, or seed coverings and the poorly competitive nature of most seedling crops means that some form of post-emergence weed control is usually necessary.

Recent research has been mostly in this area of post-emergence weed control. The introduction of specific grass herbicides such as sethoxydim and fluazifop means that grass weeds can be controlled, but broad-leaved weeds are still a major worry (19). Troublesome species include wireweed, *Polygonum aviculare*, sorrel, *Rumex acetosella*, and various species of clovers, *Trifolium* spp. Hexazinone, glyphosate (3) and oxyfluorfen (22), have proved to be too phytotoxic for routine use. Aziprotryne (22), and clopyralid are being used, but are not totally satisfactory in terms of efficacy and spectrum of weeds controlled. Further work is required therefore to develop techniques for broad-leaved weed control in nurseries.

Part of this problem also stems from too great a reliance on broad-acre herbicide application. Effective and economical nursery weed control requires an integrated appraoch, incorporating a good knowledge of weed identity and biology, vigilance, and judicious use of sanitation, hand-weeding and spot applications of herbicides.

RESEARCH PRIORITIES IN FOREST WEED CONTROL

With the high and increasing cost of weed control in forests, the most common question asked by managers is whether a particular treatment is economic, i.e. is the long-term financial benefit of controlling a particular set of weeds, expressed in the value of increased wood production, greater than the cost of treatment compounded over the production period. The long rotation length of forests, and the varying types of responses to treatments (35), makes this a complex question (27). Most weed control experiments are not designed to yield the reliable, long-term growth information necessary to answer the important economic questions. This should be addressed in future research.

Specific applied research is required to perfect techniques for establishing native trees on grasslands, for braod-leaved weed control in nurseries, and to monitor the environmental effects of both aerially and ground applied herbicides.

Forestry represents only a small market for chemicals, and there is consequently a lack of interest in product development and registration by the chemical companies. Possibly as a result much forest weed research is very *ad hoc* and applied, and the extrapolation and establishment of general principles is difficult. While local applied research is still very necessary, more basic weed research relevant to forestry needs should be encouraged. For example, the soil/herbicide and plant/herbicide interactions affecting the tolerance of pines to atrazine deserve more attention.

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