technique is also effective on *Centaurea solstitialis.*

Discussion

As with all weeds, any one technique for the control of thistles, such as herbicide application, is ineffective if not used with other techniques and management strategies in an integrated program. For several thistle species such as *C. vulgare* and *S. marianum*, herbicides used in an integrated program provide satisfactory control. However, for the biennial species such as *Onopordum* spp. the effectiveness of herbicide is wanting. For species such as *C. nutans,* trial work (Milne 1996) has shown that herbicides can be extremely successful if the correct rate and timing is observed.

The philosophy of integrated weed control is generally little understood by many graziers and to a lesser extent by agricultural extension personnel. Many control programs are often unsuccessful because one single technique, such as herbicide application is used in isolation without consideration of a long term integrated strategy. Biological control is another important aspect of thistle control (Woodburn and Briese 1996) which requires research to fit it into an overall control program.

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The relevance of variation in thistles to herbicidal control

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Summary

Variation in thistles is the result of environmental, morphological and genetic factors. The success of any strategy for thistle control could depend on one or all of these factors and on the thistle species concerned. Seasonal rainfall and temperature patterns can have a significant bearing on the behaviour of many of the thistle species common to Australia. The intensity and frequency of rainfall events can markedly affect the emergence and establishment behaviour at the early part of the growing season and the amount and germinability of the seeds formed at the end of the season. The ability of some thistle species to form biennial and perennial plants that flower over a long period results in the production of large numbers of seeds. When these seeds germinate over an extended period in a single season, the seedlings pose a managerial problem and cause economic constraints through the cost of repeated herbicide or cultural treatments. In addition, the ability of thistles to produce seeds with the potential to remain dormant over several seasons adds to the cost of any control strategy. The presence of genetically distinct forms or 'ecotypes' in several of the thistles is well documented, but there have been very few studies of the responses of these forms to cultural and chemical treatments. Studies in future should consider the morphological and physiological features of the various thistles and investigate methods to improve herbicidal control without reduced production caused by damage to the infested pasture or crop.

Introduction

Research some years ago reported differential responses to 2,4-D of some ecotypes of Canada thistle *Cirsium arvense* (L.) Scop. from locations in North Western United States of America (Hodgson 1964). Although it was indicated that further investigations were to be initiated into herbicide responses, no reference to further work on this topic by that author has been found.

More recently intraspecific variation between populations of nodding thistles *Carduus nutans* L. ssp. *nutans* in the form of resistance to the phenoxy herbicides 2,4-D and MCPA has been reported from New Zealand by Harrington (1990) and Popay and Medd (1990). The resistant populations were deemed to be just as ecologically fit as the non tolerant populations. As a result of this, chemical control strategies had to be changed to apply herbicides that were more damaging to legume based pastures.

A review on ecology and control of thistles in Australia by Sindel (1991) mentions the variability within and between species but there were few references on the influence of this variability on control using herbicides. As a result of the limited information regarding the influence of variation within a thistle species on the success of herbicide treatments, much of this paper will deal with the obvious effects within and to a lesser extent between thistle species.

Morphological variation

Thistles can range in height from about 5 cm for stemless thistle *Onopordum acaulon* L. up to 180 cm for variegated thistle *Silybum marianum* J. Gaertn. (Parsons and Cuthbertson 1992). Variation in height either between or within a species poses a problem when applying herbicides by boom sprayers as the correct spray overlap cannot be achieved. This tends to lead to some strips being overdosed with chemicals while others receive sub lethal amounts. Additionally many of thistles are so tall that it is impossible to raise a conventional boom sprayer high enough to travel over the top of the infestation, and other methods for applying the chemical may be more appropriate.

The surface features of rosette and stem leaves and bracts surrounding the flowers could play an important part in herbicide retention and penetration. Evidence suggests that the droplet size has an important bearing on the amount of chemical taken in from various leaf surfaces (Hess *et al.* 1974). Small droplets are usually ineffective on very hairy plants because most of the droplets are retained on hairs with very little reaching the leaf surface. Larger droplets have a better chance of reaching the leaf surface of hairy plants because they shatter on the hairs, allowing some of the smaller droplets formed to contact the surface. The reverse can occur with smooth plant surfaces. Large droplets shatter and bounce or collect into larger deposits which can run off.

Translocated herbicides, such as glyphosate, 2,4-D or MCPA and contact herbicides such as diquat, paraquat and bromoxynil applied in small droplets (low volumes), may be more effective on the less hairy species, such as saffron thistle *Carthamus lanatus* L. and glaucous star thistle *C. leucocaulos* Sibth. and Sm. Higher volumes (larger droplets) may be required on hairy thistle plants such as African thistle *Berkheya rigida* (Thunb.) Bolus and Wolley-Dod, and the *Cirsium* and *Onopordum* species (Table 1).

Apart from some data from research on the effect of varying spray droplet diameters on control of grasses, there is limited information on broad leaved species such as thistles on the effect of droplet size, density and concentration of chemical as influenced by volume of application. Considerable work has been carried out on insects and it has been shown that volume of application / droplet size and chemical concentration have a pronounced influence on the effectiveness of control treatments (Smith *et al*. 1979). In addition to changing volumes of application and droplet sizes no information is available on the effect of various adjuvants, penetrants and anti-evaporants. Richardson (1981) reported that *S. marianum* showed no response to varying droplet sizes from 172–461 µm, but did have a minimum requirement of 10 droplets cm^{-2} for adequate control. The dose rate or the concentration of the chemical in the droplet applied to that thistle was shown to be more important than the other factors.

Differences in leaf area of the various thistles in the early rosette stage may determine the amount of chemical taken up. Rosette leaves of *Carthamus lanatus* have a very small surface area compared to *S. marianum*, *O. acanthium* L. and *Cirsium vulgare* (Savi) Ten.

Table 1. Texture of rosette and stem leaves of some thistles.

Rosette leaves		Stem leaves	
Hairy	None to slightly hairy	Hairy	None to slightly hairy
	Nodding thistle *Carduus nutans*	African thistle *Berkheya rigida*	Slender thistle
Star thistle *Centaurea calcitrapa*	Slender thistle *Carduus pycnocephalus*	Nodding thistle	Glaucous thistle
St. Barnaby's thistle *Centaurea solstitialis*	Saffron thistle *Carthamus lanatus*	Saffron thistle	Star thistle
Perennial thistle *Cirsium arvense*	Glaucous star thistle *Carthamus leucocaulos*	St. Barnaby's thistle	Perennial thistle
Spear thistle *Cirsium vulgare*	Variegated *Silybum marianum*	Spear thistle	Spotted thistle *Scolymus maculatus*
Artichoke thistle *Cynara cardunculus*		Artichoke thistle	
Scotch thistle *Onopordum acanthium*		Scotch thistle	
Stemless thistle *Onopordum acanthium*		Illyrian thistle	
Illyrian thistle *Onopordum illyricum*		Golden thistle *Scolymus hispanicus*	
Soldier thistle *Picnomon acarna*		Variegated thistle	

Table 2. Germination period for a range of thistles found in Australia.

	Autumn	Winter	Spring	Summer
Artichoke thistle	•*	•	•	•
Scotch thistle	•	•	•	•
Stemless thistle	•	•	•	
Illyrian thistle	•*	•	•	•
Soldier thistle	•			
Golden thistle	•	•	•	
Spotted thistle	•	•		
Variegated thistle	•*		•	
African thistle	•			
Nodding thistle	•	•	•	•
Slender thistle	•			
Saffron thistle	•	•		
Glaucous star thistle	•			
Star thistle	•			•
St. Barnaby's thistle	•			
Perennial thistle	•		•	
Spear thistle	•	•	•	•

* Main germination period.

Phenological variation

In most thistles, germination is staggered over a period of weeks / months (Table 2), so in any population there could be a range of plants at different growth stages. This creates two problems. Firstly any treatment early in the season to control rosettes may be only partially successful as there is the probability that further germinations will occur. The asynchrony in seedling emergence of *Carduus nutans* was recognised as a reason for delaying treatment until spring so that only one application in a year is needed (Medd and Lovett 1978). The extra treatments required to control the new germinations can make the treatment costly and time consuming, as well as causing further set backs to other pasture growth. Applying treatments after 'full' germination could result in more severe pasture damage because the dose rate of chemicals required to control large rosettes from early germinations is often higher.

Germination patterns of thistles can vary between locations and also between years, the latter being influenced by interactions of dormancy mechanisms, soil temperatures and rainfall patterns (Forcella and Wood 1986, Groves and Kaye 1989, Forcella and Randall 1994). This effect was shown on saffron thistle when seeds from one area were planted at two other locations to the north and south of its distribution in Western Australia. Seed planted in the north at a warmer site gave almost a single emergence pattern while at the cooler location in the south, emergence was staggered over several months (Peirce 1990).

Stem elongation in short-season annuals such as slender thistles, *Carduus pycncocephalus* L. and *C. tenuiflorus* Curtis, is delayed considerably as a result of delayed germination (Groves and Kaye 1989). Flowering in these two thistles was also retarded as the time of germination was delayed. In most other thistles, however, the variation in time of germination was not reflected in delayed stem elongation and flowering, hence any control measures to treat flowering plants should be successful, provided flowering of capitula was not spread over a long period of time. Control of *C. lanatus* at flowering has been quite effective in Western Australia (Peirce 1992), where full flowering was achieved within 14 days of the first capitulum reaching anthesis. Successful control at flowering of *C. lanatus* was also reported in South Australia by Fromm

(1990). However, in eastern Australia this successful method of treatment may not be applicable as flowering of *C. lanatus* can occur over 30–60 days at Canberra (Groves and Kaye 1989) and about 60 days at Wagga Wagga (Forcella and Wood 1986). This could be due to the higher summer rainfall which may permit treated capitula to recover or new capitula to form as the treatments are usually only causing severe damage to the capitula and not to the remainder of the plant structures.

Conclusions

The many studies on thistles both in Australia and overseas indicates that considerable variability does exist. The relevance of this to successful control strategies has not been fully investigated but could be a direction for any further research. More effective chemical application may be achieved by a better understanding of the behaviour of herbicides in combinations with the numerous additives that are now available. In addition some knowledge would be useful as to what effect the cuticle layer and other external structures on the leaf surface in the numerous thistles is having on the movement of herbicides into the plant.

The exploitation of the height difference between thistle and pastures may be utilized by more research into the techniques using wiping as a method to apply the herbicide.

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Practical problems with existing thistle control: Where is more research needed?

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Summary

Many practical problems exist with current thistle control techniques. Integrated control/management programs are necessary on properties, as well as continued research into alternative control methods. This paper summarizes problems with current thistle management, viewed from the perspective of a regional noxious plants control authority, and discusses some steps that are needed to improve the situation.

Introduction

The Southern Slopes Noxious Plants Authority (SSNPA) was established in 1992 and incorporates the Shires of Harden, Young, Yass and Boorowa in south-eastern New South Wales. The control area is located at Boorowa. The main objectives of the Authority are to:

- control noxious plants on all council lands
- enforce noxious plant control on privately owned land, reserves and crown lands
- advise and educate landholders
- initiate control programs for landholders
- provide a contract spraying facility.

One of four levels of control categories may be placed on declared noxious plants:

W1 – presence of the weed on land must be notified to the Local Control Authority and the weed must be fully and continuously suppressed and destroyed,

W2 – must be fully and continuously suppressed and destroyed,

W3 – must be prevented from spreading and its numbers and distribution reduced,

W4 – action specified in the declaration must be taken in respect to the weed.

Four species of thistle are currently declared noxious throughout the SSNPA area; scotch (*Onopordum acanthium*), Illyrian (*O. illyricum*) and stemless (*O. acaulon*) which have all been placed in the W3 category, and nodding (*Carduus nutans*) which has been placed in W2. Thistles are the most widespread of all the declared noxious weeds in our area with scotch and Illyrian thistles being the most prevalent. The Harden Shire, which takes in Jugiong, is heavily infested with these, and that is the reason for their W3 categorization. Stemless and nodding thistle are less abundant in the area.

Current control methods and problems in their application

The following control methods are used in the battle against thistles:

- herbicide spraying
- cultivation
- grazing / spray grazing
- pasture sowing as competition
- biological control.

A combination of several, if not all, of these methods are used by property owners to attempt to stop the spread of thistles. Unfortunately once the scotch / Illyrian thistles become established, it is difficult and expensive to eliminate them and programs are reduced to halting their further spread into clean country.