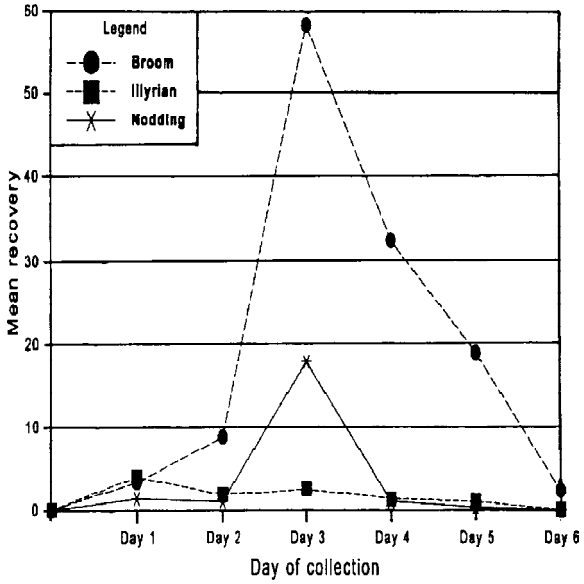

Figure 2. Average number of seeds of Illyrian thistle, scotch broom and nodding thistle, recovered from four goats.

can control the amount of seed entering the soil they represent an important technique and should be part of the integrated control of thistles.

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Herbicide management and thistle control—how to avoid resistance

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Summary

Applying phenoxy herbicides annually to thistles for many years can lead to herbicide resistance developing within thistle populations. Populations of nodding thistle have been located in Hawkes Bay which require six times more MCPA than normal to obtain adequate control. Such populations are known to exist on at least 12 properties in Hawkes Bay and Waikato. A comparison of past spraying practices on these properties and farms where resistance has not developed identified that resistance has occurred due to more frequent use of phenoxy herbicides on the former properties. Cross-resistance exists within these populations to 2,4-D, MCPA and MCPB. Thus such thistles can only be controlled by adding clopyralid to one of these herbicides, which is damaging to pasture legumes. Work with radio-labelled MCPA has shown that resistance is due to an increased rate of herbicide degradation within the plant rather than reduced uptake, so adding surfactants to the herbicide will not overcome the resistance.

Based on research results from a range of sources, the following recommendations could be made. Intense herbicide pressure can be justified on thistle species which are just establishing on a property. However, once populations have well established seed banks, a better strategy may be to rely mainly on good pasture management techniques to reduce the impact of weeds which are present. Sowing pasture species tolerant of dry conditions is probably the most useful pasture management strategy. Ensuring that these pastures are not overgrazed in summer and early autumn should help reduce establishment of the seedlings each autumn. Grazing paddocks with cattle rather than sheep can avoid overgrazing, and goats can reduce seed production by eating the seed-heads. Farmers may need to be more tolerant of low thistle numbers, and spray only in those years when densities are high. Thus resistance will be less likely to develop, so thistles will still respond to herbicides in those years when control is really necessary.

Introduction

Although it was once thought that herbicide resistance was unlikely to develop in weed species sprayed with phenoxy herbicides, work in New Zealand has shown that populations of nodding thistle (*Carduus nutans*) have become resistant to MCPA and 2,4-D through their continued use (Harrington 1990). The aim of this paper is to outline the work that has been conducted in New Zealand to study herbicide resistance in nodding thistle and to offer suggestions as to how farmers could avoid herbicide resistance developing in this and other thistle species growing in pasture.

Herbicide resistance in New Zealand thistles

Poor control of nodding thistle at Argyll in Hawkes Bay during the early 1980s prompted tests to be conducted to check whether resistance may have developed in the population. As the development of resistance to phenoxy herbicides had rarely been documented before this time, poor control was assumed to be due to environmental factors. However when nodding thistle from Argyll was grown from seed in a glasshouse beside nodding thistle from another site where satisfactory control was still being obtained, a significant difference in susceptibility was detected (Harrington and Popay 1987). Sizeable differences in susceptibility to MCPA were detected each time this comparison

was repeated both in the glasshouse and in the field, and it was calculated that nodding thistle from Argyll was six times less susceptible to MCPA than normal (Harrington *et al.* 1988).

Nodding thistle seed was collected from a number of other sites in Hawkes Bay and Waikato where farmers had complained of obtaining poor control using 2,4-D. Plants from at least 12 of these sites showed similar levels of resistance to those plants at Argyll, showing that this resistance was not an isolated incident (Harrington 1989).

A range of different herbicides was applied at their recommended rates to field-grown plants of a susceptible and resistant population planted beside each other. Cross-resistance was detected to MCPA, 2,4-D and MCPB (Harrington 1989), the three herbicides normally used for selective control of nodding thistle in New Zealand pastures. Although there was no cross-resistance to herbicides such as dicamba, clopyralid or picloram, these herbicides all cause severe damage to clovers in pastures. The standard recommendation at present for controlling herbicide-resistant nodding thistles is to add a low rate of clopyralid to standard rates of 2,4-D or MCPA (Harrington 1993), though this can cause unacceptable levels of clover damage.

To determine whether resistance was due to poor herbicide absorption, ^{14}C-labelled 2,4-D was applied to the foliage of resistant and susceptible nodding thistle plants. No significant differences in penetration were recorded (Harrington 1992). However there were significantly lower levels of unmetabolized 2,4-D detected in resistant plants 7 days after application than in susceptible plants. It appeared that resistance resulted from 2,4-D molecules being converted into both water soluble and ether soluble metabolites more rapidly than in susceptible plants. Thus adding surfactants to increase uptake of the herbicide would be unlikely to overcome the resistance. Although surfactants might improve uptake of herbicides despite this, clovers are also likely to become more susceptible to the herbicide.

To determine why herbicide resistance developed in nodding thistle, the previous spraying histories for seven sites with resistance and seven sites free of resistance were studied. All sites with resistant populations had been sprayed at least annually every year for the previous 15 years or longer with 2,4-D or MCPA (Harrington 1990). The susceptible sites had also been sprayed in previous years, but they had all been sprayed much less frequently. Presumably this would allow susceptible plants to cross-pollinate with resistant plants in the years when herbicides were not applied, though perhaps even sites sprayed infrequently may eventually develop resistance in future years. No work has yet been done to determine whether resistance is caused by one or many genes, or whether the genes are dominant or recessive.

Likewise, few studies have been completed on whether resistant thistles are less 'fit' than susceptible thistles. A trade-off with fitness of plants is often noted when resistance develops to herbicides (Gressel and Segel 1982). However a preliminary trial in which resistant and susceptible plants grew beside each other in a 1:1 ratio under severe nutrient stress showed no significant differences between ecotypes in their reaction to this stress (Harrington 1990). Since that trial was conducted however, Bourdôt *et al.* (1996) have detected reduced growth from MCPA-resistant giant buttercup (*Ranunculus acris*) plants when grown at high densities with susceptible biotypes.

Avoiding development of herbicide resistance in other thistle populations

Since the development of resistance to 2,4-D in nodding thistle was recorded in Hawkes Bay, a similar phenomenon has been noted with resistance to MCPA in giant buttercup elsewhere in New Zealand (Bourdôt *et al.* 1989). Likewise resistance to MCPA appears to have developed in slender winged thistle (*Carduus pycnocephalus*) in Hawkes Bay, but further work is required to conclusively prove this (Harrington 1989). So there can be no doubt that farmers in New Zealand are able to exert sufficient selection pressure with phenoxy herbicides to develop herbicide resistant biotypes. Once this resistance has developed, these weeds can become very difficult to control. Thus it would be preferable to avoid resistance from developing initially.

Herbicides could be used less frequently if thistle densities could be kept low. Many studies have shown that thistle establishment is less likely if pastures remain dense throughout the year (e.g. Phung and Popay 1981, Popay *et al.* 1987). Many thistle problems occur as a result of pasture covers opening up during periods of dry weather, leaving bare soil where thistles can germinate when rain falls in autumn. However there are now a number of pasture species which are being successfully established in areas of New Zealand prone to summer drought, including 'Grasslands Wana' cocksfoot, 'Grasslands Maru' phalaris and 'Grasslands Roa' tall fescue (Milne *et al.* 1993). Establishment of such pastures make it easier for farmers to keep pastures dense throughout the year, making thistle invasion less likely.

Pastures will be more difficult to keep dense and competitive during summer if there is too much livestock on the property. Farmers need to carefully consider whether their stocking rate should be reduced over summer if thistle problems in the following season are to be avoided. Use of supplementary feed crops over summer to reduce the grazing pressure on pastures is another possible strategy. Cattle often do not graze pasture as close to the ground as sheep, so increasing the ratio of cattle on a property can help reduce thistle problems. One farmer in Waikato who had problems with herbicide-resistant nodding thistle completely changed his farming system from sheep to cattle and found nodding thistle was much less of a problem. Note however that ragwort (*Senecio jacobaea*) then became the dominant weed on his property. Goats can also be useful on properties with thistle problems as they often eat the seedheads, reducing the quantity of seed produced each year (Rolston *et al.* 1981). Likewise biological control agents such as *Rhinocyllus conicus* should be encouraged as they can reduce seed production from some thistle species (Kelly *et al.* 1990).

Farmers also need to learn how to tolerate low densities of thistles and to only spray in those years when densities are particularly high. If MCPA or 2,4-D is used rather than MCPB for thistle control, animal production can suffer temporarily due to a reduction in clover production. Hartley (1983) showed that spraying thistles was not justifiable economically for densities below 1.7 m^{-2} because animal production was affected more by the herbicide than thistles below this density. Farms, where a policy of spraying only when really necessary had been adopted, had no herbicide resistance problems. Those where resistance had developed had been trying in vain for many decades to eradicate nodding thistle from their properties. Such eradication is apparently seldom achieved on properties where seed banks are well established. Intense herbicide pressure should probably only be applied when a new thistle species is just becoming established on a property. If densities of such a species are low enough that it is practical to kill survivors of a spraying operation each year by grubbing or spot-spraying with herbicides such as clopyralid, then eradication may be possible and development of resistance less likely. Noxious plants schemes should be designed to ensure that farmers are not being forced to attempt eradication of a thistle species from their property once seed banks are well established.

A meeting was convened in Napier during November 1995 at which invited farmers, advisors and scientists discussed what further research was required to assist Hawkes Bay farmers cope with thistle problems, including herbicide resistance. One of the main conclusions from this meeting was that scientists have a reasonable understanding of what needs to be

done on farms to overcome thistle problems, but that farmers and often also the advisors are not aware of the research that has been completed over the past 20 years or the implications of these findings. Thus in the short term, improved extension activities were seen to be more important than further research. If farmers were more aware of the concepts discussed above, herbicide resistance would be less likely to develop on their farms. Note however that the lack of a testing service in New Zealand to confirm the presence of herbicide resistance in thistle populations can cause problems for advisors.

Conclusions

The development of herbicide resistance in thistle populations can and does occur. Once resistance is present, selective control of these weeds with herbicides is very difficult to achieve. Farmers should avoid resistance from developing at all by reducing the selection pressure applied by herbicides. They should try to keep their pastures competitive enough in late summer and autumn to prevent thistles establishing from seed. They should tolerate low densities of thistles and only apply herbicides in those years when densities are particularly high.

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