APPLICATION TIME INFLUENCES THE DEVELOPMENT OF HERBICIDE RESISTANCE IN GIANT BUTTERCUP (*RANUNCULUS ACRIS*)

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SUMMARY

A simulation model reproducing the phenology of giant buttercup (*Ranunculus acris* L.) was used to evaluate the effect of application time on the development of herbicide resistance. The analysis suggests that the usual winter or spring applications of MCPA not only prevent seed set by susceptible phenotypes but also expose a high proportion of the buttercup population to the herbicide. By contrast, MCPA applications which follow flowering allow recruitment of susceptible seed and also expose a much smaller proportion of the population to the herbicide. The resulting delay in the development of resistance is likely to be significant but there may be a short term cost through loss of pasture production.

Keywords: *Ranunculus acris*, giant buttercup, herbicide resistance, MCPA, simulation model

INTRODUCTION

Giant buttercup (*Ranunculus acris*) is an important weed in dairy pastures throughout much of New Zealand's North Island (Popay *et al* 1984), and in the Golden Bay region of the South Island (Bourdôt *et al* 1990a). Giant buttercup has been controlled with MCPA or MCPB at a rate of 1.0 kg/ha (Tuckett 1961), particularly with August/September applications (Matthews 1975).

The effectiveness of MCPA against giant buttercup is now under threat from the emergence of populations of the weed showing genetic resistance to this herbicide (Bourdôt and Hurrell 1988; Bourdôt *et al* 1990a, 1990b). On some farms buttercups have reached levels of resistance such that control would require rates of MCPA as high as 10 kg/ha (Bourdôt and Hurrell 1988). These would be unacceptable due to the resultant clover damage and the high cost. Resistance has been confirmed at many sites in both the North and South Islands (Bourdôt *et al* 1990a, 1990b), and with continued herbicide use it can be expected to increase both in severity and distribution.

An investigation of factors likely to delay the development of MCPA-resistance is therefore highly desirable. In this paper we use a modelling approach to investigate the likely effect of different application times on the development of herbicide resistance.

METHODS

The model is a computer simulation designed to reproduce the phenology of giant buttercup in New Zealand. Three age classes are recognized; seed in the soil, seedlings and mature plants. The seasonal patterns of germination and seed set were taken from field observations in New Zealand (Popay *et al* 1989; Bourdôt unpublished), and constant mortality rates for seed (0.0573/week), seedlings (0.0691/week) and mature plants (0.0066/week) were estimated from the data of Sarukhan and Harper (1973) and Sarukhan (1974). From relationships outlined in Sarukhan and Harper (1973) and field observations in New Zealand (Bourdôt unpublished) the number of seeds set was assumed to increase with plant density up to a maximum of 4500 seeds/m² at 25 plants/m², after which seed set declines toward zero at 50 plants/m².

Although vegetative reproduction occurs in giant buttercup, it is not considered significant (Sarukhan 1974). Popay *et al* (1989) reported small clumps of three to six

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buttercup plants although they did not determine whether these were the result of vegetative budding from a single parent or from the simultaneous germination of seeds in a patch of bare ground (A.I. Popay pers. comm.). Any offspring produced vegetatively would have an identical genotype to the parent, and so we did not include this mechanism of reproduction in the model for investigating changes in resistant gene frequency.

While the presence of a genetic mechanism for MCPA resistance in giant buttercup has been demonstrated (Bourdôt and Hurrell 1991), its nature is unknown. However, a single gene mechanism was assumed as in almost every case of field-derived resistance which has been studied in detail, the mechanism has proven to involve only a single gene (McKenzie 1986). To ensure that the results were independent of the other components of the resistance mechanism, the model was run under a range of assumed resistance characteristics (e.g., fitness of the resistant genotypes, dominance of the resistance **R** gene). Dose-mortality data from Bourdôt and Hurrell (1988) were used to estimate percentage kill of susceptible genotypes and this was assumed to be constant throughout the year. Further details of the model may be obtained from the senior author.

The model was used to simulate an annual application of MCPA at 1.0 kg/ha for five years, and the mean annual increase in the frequency of the **R** gene was calculated. The outcome of applying the herbicide in different months of the year was compared.

RESULTS

The phenology of giant buttercup, as simulated in the model, is outlined in Figure 1. Seed production increases rapidly to a peak in January and falls off to zero in May (Fig. 1a). The density of soil-borne seeds (Fig. 1b) fluctuates over the year due to

Fig. 1: Seasonal pattern of a) seed production b) density for a single cohort of seed over two consecutive years (hence two lines) and c) seed germination as simulated in the model for giant buttercup in New Zealand.

seasonal germination (Fig. 1c), seed input from mature plants and seed mortality. Model output is consistent with current understanding of the dynamics of giant buttercup in the field. For example, when repeated annual herbicide applications against a susceptible population are simulated, there is a rapid decline to low populations levels as observed in the field by Bourdôt and Hurrell (1990a). When herbicide applications cease the model predicts a return to an equilibrium population density over 3 to 4 years, as has been measured in the field by Popay *et al* (1989).

Model output suggests that the timing of herbicide application has a significant impact on the rate of development of resistance. The increase in the **R** gene caused by MCPA applied in different months is shown in Fig. 2a (note log scale). Spraying in October/November leads to rates of increase in the **R** gene several orders of magnitude greater than spraying in mid summer/early autumn. Although the model's prediction of the rate of development of resistance was sensitive to some of the parameter values used (e.g., the initial frequency and level of dominance of the **R** gene and the death rate of seed in the soil), the effect of timing of herbicide applications remained constant. This insensitivity to assumptions regarding the resistance mechanism implies that the effect of application time results from ecological factors relating to the phenology of giant buttercup.

Further analysis suggested that the differences in the rate of development of resistance relate to the proportion of the population (seeds plus growing plants) exposed to the herbicide. This proportion varied with month of spraying in a similar way to the increase in **R** gene frequency (Fig. 2b).

Fig. 2: The predicted effect of timing of MCPA application on a) the rate of buildup of the resistance (**R**) gene and b) the proportion of the population exposed to the herbicide.

DISCUSSION

This simple model has allowed an investigation of the factors likely to be significant in the development and management of herbicide resistance in giant buttercup. Little detail is known of the phenology of giant buttercup in New Zealand or of the mechanism of MCPA resistance. Also, the validity of extrapolating the ecological parameters recorded in Wales by Sarukhan and Harper (1973) and Sarukhan (1974) to

New Zealand is uncertain. However, even when specific parameter values are unknown or uncertain the model can be run using a range of possible values to examine the effect on output. Only outputs which are robust under a range of parameter values are considered.

Output from the model suggests that altering the timing of herbicide application will result in large differences in the rate of buildup of MCPA resistance in giant buttercup. Furthermore it suggests that these differences largely reflect the proportion of the population exposed to the herbicide at different times of the year. In the presence of a large, long-lived seed bank the proportion of a weed population represented by above ground plants would be relatively small all year round and so the timing of herbicide application would be less critical. However, in giant buttercup where the majority of seed survives less than 12 months, at certain times of the year the above ground plants comprise a significant proportion of the total plant population. Thus an effective herbicide applied in the spring prior to the beginning of flowering not only prevents any susceptible phenotypes from setting seed (Bourdôt *et al* 1990a), but also exposes a high proportion of the total population to the herbicide, resulting in a high selection pressure for resistant phenotypes. The model's sensitivity to variations in seed bank survival support this hypothesis.

Tuckett (1961) found that MCPA at 1.5 kg/ha gave very satisfactory control of giant buttercup when applied in February, March, October, November, or December, and that the February and March applications caused less clover damage. Popay *et al* (1984) found that in some seasons applications of 1.0 kg/ha in April, May, October or November gave effective control, although August/September applications were best. However, some of the populations on which Popay *et al* (1984) were working have subsequently been found to possess a level of resistance to MCPA (Bourdôt *et al* 1990b) and this may have influenced the amount of control achieved at certain times of the year. These results suggest that there may be scope for controlling giant buttercup with other than spring applications of herbicide (e.g., February to May) which would significantly reduce the selection pressure for resistance.

Ultimately the continued use of MCPA against giant buttercup will be a compromise between maximising the short term benefits of control against the long-term consequences of genetic resistance, particularly as there are no suitable alternative chemicals. The current analysis suggests that reductions in selection pressure attainable by timing of herbicide applications are likely to be significant. However, before a firm recommendation can be made the short term cost in pasture production associated with different application times will need to be evaluated. This work is in progress.

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