Control of ragwort (*Senecio jacobaea* L.) at advanced stages of growth using clopyralid

D. A. Friend
Department of Agriculture, P.O. Box 46, South Launceston, Tasmania 7249

Summary

Clopyralid applied as a spot spray to ragwort at the late rosette and shooting stages completely prevented seed production and gave a very high level of mortality at rates as low as 0.3 g l⁻¹, although the level of control did not exceed that obtained from the currently recommended herbicide for use at these times, 2,4-D ester at 4.0 g l⁻¹.

Clopyralid at 0.6 g l⁻¹ was more effective than 2,4-D at 4.0 g l⁻¹ in reducing the production of viable seeds when applied in the period from just prior to flowering to just prior to seeding. No seeds were produced by plants sprayed with clopyralid before the appearance of the first flowers, but the weight of seeds produced and their germinability increased as spraying was delayed after flowering.

For complete prevention of seed production at flowering it was necessary to use diquat in combination with clopyralid or 2,4-D. Clopyralid at 0.3 g l⁻¹ together with diquat at 2.0 g l⁻¹ also gave a very high level of control of regrowth of treated plants, a result similar to that obtained with the currently recommended herbicide, 2,4-D ester at 2.4 g l⁻¹ in combination with diquat at 2.0 g l⁻¹.

Introduction

Ragwort (*Senecio jacobaea* L.) is a troublesome pasture weed in the higher rainfall areas of south-eastern Australia, including Tasmania (Fricke 1944; Schmidl 1972). In these situations the plant commonly behaves as a perennial, with an extended period of vegetative growth during which it develops a large root system with a large crown, often supporting several rosettes (Cairns 1938).

The herbicide most widely used to control ragwort at the rosette stage is 2,4-D (Watt 1987). In Tasmania, spot treatment with 4.0 g l⁻¹ of 2,4-D ester is currently recommended for control of these large multi-crown plants (Anon. 1985) but even at such a high rate of herbicide there may be an unacceptable amount of regrowth (Friend, personal observations).

Susceptibility to 2,4-D decreases markedly following stem elongation, but control measures are often delayed until this stage of growth, or even until flowering, where isolated plants are difficult to find at the rosette stage. Control of flowering requires the use of diquat to prevent viable seed formation. This herbicide gives rapid destruction of the top growth and, combined with 2,4-D, also gives a high degree of control of regrowth from the crown and roots of sprayed plants. However, observations have shown that the amount of regrowth from treated plants may often be sufficient for the infestation to re-establish in the following year (Friend, personal observations).

The need for alternative herbicides to 2,4-D is heightened by the recent controversy concerning its possible damaging effects on human health and the environment (e.g. Backstrom 1978; Pemberton 1979; Severson 1980; Hoar *et al.* 1986). Glyphosate, picloram, dicamba, chlorthiamid, dichlobenil and asulam have been evaluated elsewhere as alternatives to 2,4-D for controlling ragwort (Thompson 1974, 1977, 1983; Makepeace and Thompson 1982), but none has proved entirely satisfactory.

Clopyralid (3,6-dichloropyridine-2-carboxylic acid) is a relatively recent post-emergence herbicide active against many weed species from the families Compositae, Polygonaceae, Umbelliferae and Leguminosae (Haagsma 1975; Naish 1975). It is absorbed by leaves and roots and readily translocated, producing characteristic growth-regulator-type responses in susceptible plants. Its potential for use against ragwort at the rosette stage has been demonstrated elsewhere (Naish 1975; Richards *et al.* 1983).

The three trials reported here were carried out to evaluate the efficacy of clopyralid for use against ragwort at advanced stages of growth as an alternative to 2,4-D. The first trial was to examine the efficacy of clopyralid at three stages of growth of ragwort from late rosette to flowering. The second trial was to examine more closely the effect of time of application of clopyralid during flowering on viable seed production. The third trial was to re-examine the use of clopyralid in combination with diquat at flowering.

Materials and methods

The trials were conducted in three different years on separate sites near Deloraine in northern Tasmania.

Trial 1

This trial was carried out in the spring and summer of 1983–84 on a site carrying a well-established ragwort infestation on a former dairy pasture. Apart from ragwort, the site was dominated by *Agrostis tenuis**, *Holcus lanatus*, *Vulpia bromoides* and *Trifolium subterraneum*. The site had been grazed by sheep the previous summer and autumn to limit flowering and seed production of ragwort, which had led to the development of a ragwort population dominated by large multi-crown rosettes.

Herbicides were applied to the ragwort plants as spot sprays at three stages of growth: late rosette (or 'cabbage' stage; applied 21 October), shooting (applied 15 December) and flowering (prior to the first flowers turning brown; applied 19 January). Clopyralid (as Lontrel L) was used alone at three rates, 0.3, 0.6 and 1.2 g l⁻¹ on each occasion, and at 0.3 and 0.6 g l⁻¹ in combination with diquat at 2.0 g l⁻¹ at flowering. A surfactant was added where diquat was used. 2,4-D as the ethyl ester formulation was used alone at 4.0 g l⁻¹ at the late rosette and shooting stage, and at 2.4 g l⁻¹ in combination with diquat at 2.0 g l⁻¹ plus a surfactant at flowering. These later treatments are the standard herbicide treatments currently recommended in Tasmania for control of ragwort at the three respective stages of growth. An unsprayed control was also included for comparison.

The herbicides were applied using a knapsack sprayer fitted with a Spraying Systems Co. TeeJet flat fan 65015 tip. Sufficient material was applied to wet the plants thoroughly.

The treatments were applied to the ragwort plants in 2 × 10-m plots. The clopyralid treatments were replicated four times at each growth stage; the 2,4-D treatments were replicated six times at the late rosette and shooting stage and eight times at flowering; the unsprayed plots were replicated eight times. Increasing the replication on the standard treatments and controls was to provide for greater accuracy in making the main comparisons, i.e. between the clopyralid treatments and the standard treatment or the control.

The plots were laid out in four blocks, each containing one replicate of the clopyralid treatments and one or two replicates of the standard treatment for each of the three times of application, and two replicates of the unsprayed control. The plots were located at random within each block.

Observations were confined to 20 plants in each plot. The plants were identified prior to the initial treatments being applied in October by their positions in a plot in relation to a 10-m tape placed down the centre of the plot, and a 2-m ruler running across the plot at right angles to the tape. Observations were made on five occasions (Table 1*a*) and included, for each plant, mortality of the top growth, vegetative regrowth, and production and germinability of seeds.

Seeds were collected on two occasions by bending the plant over and shaking the inflorescence inside a polythene bag. Germination tests were carried out on moistened filter paper pads at 20°C under a 16-h photoperiod for 14 days.

Final observations were made in August 1984 when the root systems of all plants with no living material above ground were excavated to check whether there were any living roots.

*Nomenclature follows Hartley (1979).

Table 1 Trial 1: effect of the herbicide treatments applied at three stages of growth on mortality of ragwort plants.

(*a*) Number of plants with living top growth out of 20 plants observed on five observation dates (means of eight replicates for control and 2,4-D plus diquat treatment at flowering; means of six replicates for 2,4-D treatment at late rosette and shooting; means of four replicates for clopyralid treatments on each occasion)

		Herbicide treatment[A]														
		Late rosette				Shooting				Flowering					
Date observed	Control	E	C 0.3	C 0.6	C 1.2	E	C 0.3	C 0.6	C 1.2	E +D	C 0.3 +D	C 0.6 +D	C 0.3	C 0.6	C 1.2
9.i.84	20	2.0	5.2	1.2	0	20	20	20	20	–	–	–	–	–	–
27.ii.84	20	0.8	1.0	0	0	3.5	16.8	10.2	1.2	0.6	0	0.2	20	20	20
27.iii.84	20	0.6	0.2	0	0	0.8	10.0	3.5	0.5	0.5	0	0.2	20	20	20
30.v.84	7.0	0.3	0.2	0	0	0	1.5	0	0	0.8	0.2	0	7.0	0.8	0.2
30.viii.84	6.2	0.3	0	0	0	0	0.5	0	0	0.5	0.2	0	2.2	0	0

[A]Herbicide treatment:
E = 2,4-D ester at 4.0 $g\ l^{-1}$
C 0.3 = clopyralid at 0.3 $g\ l^{-1}$
C 0.6 = clopyralid at 0.6 $g\ l^{-1}$
C 1.2 = clopyralid at 1.2 $g\ l^{-1}$
E + D = 2,4-D ester at 2.4 $g\ l^{-1}$ plus diquat at 2.0 $g\ l^{-1}$
C 0.3 + D = clopyralid at 0.3g l^{-1} plus diquat at 2.0 $g\ l^{-1}$
C 0.6 + D = clopyralid at 0.6 $g\ l^{-1}$ plus diquat at 2.0 $g\ l^{-1}$

Levels of significance of the treatment effects

Source of variation	Time of application: Late rosette	Shooting	Flowering
Date observed	$P < 0.001$	$P < 0.001$	$P < 0.001$
Control *v*. herbicide	$P < 0.001$	$P < 0.001$	$P < 0.001$
Between herbicides	$P < 0.001$	$P < 0.001$	
Date observed × (control *v*. herbicide)	$P < 0.001$	n.s.	n.s.
Date observed × herbicide	$0.01 < P < 0.025$	n.s.	$P < 0.001$

(*b*) Number of plants with living roots out of 20 plants observed on 30.viii.84 (means of eight replicates for control and 2,4-D plus diquat treatment at flowering; means of six replicates for 2,4-D treatment at late rosette and shooting; means of four replicates for clopyralid treatments on each occasion)

	Herbicide treatment[A]													
	Late rosette				Shooting				Flowering					
Control	E	C 0.3	C 0.6	C 1.2	E	C 0.3	C 0.6	C 1.2	E +D	C 0.3 +D	C 0.6 +D	C 0.3	C 0.6	C 1.2
7.2	0.3	0	0	0	0	0.8	0.2	0	0.5	0.2	0	6.0	0.2	0

[A]See footnote for Table 1*a*.

Levels of significance of the treatment effects

Source of variation	
Control *v*. herbicide	$P < 0.001$
Between herbicides	$P < 0.001$
Time of application × (control *v*. herbicide)	$P < 0.001$
Time of application × herbicide	n.s.

The significance of the treatment effects on plant mortality were determined using a generalized linear model with binomial error structure and complimentary log log link (McCullagh and Nelder 1983) to analyse the data relating the number of plants surviving to a particular observation date to the number living at the previous observation.

The data on germinability of seeds were analysed in the same way as the plant mortality data. However, the residual deviance was too high for the assumed binomial model, so the ratios of the mean deviances to the residual mean deviance were compared to the *F* distribution as in an analysis of variance.

Trial 2

This trial was carried out in the summer of 1985–86 on a dairy pasture sown down following cropping 2 years previously. A dense population of large multi-stemmed flowering plants was present, apparently having developed from plants not killed by cultivation in the cropping period. Besides ragwort, the main pasture species were *Lolium perenne, Trifolium repens, T. pratense, Cirsium vulgare, Plantago lanceolata* and *Hypochoeris radicata*.

Herbicides were applied as spot sprays at three stages during the flowering period: pre-flowering (applied 10 January), when the older flowers were still in bud, but were beginning to show a tinge of yellow; flowering (applied 23 January), when the older flowers were at anthesis and showing their full yellow colour; and pre-seeding (applied 6 February), when the older flowers were turning brown.

Clopyralid was applied alone at one rate, 0.6 g l^{-1}, at each stage. 2,4-D as the iso-octyl ester was applied alone at 4.0 g l^{-1} at each stage, and in combination with diquat at 2.0 g l^{-1} plus a surfactant at the second, flowering stage. An unsprayed control was again included. Application was by the same knapsack sprayer used previously, with sufficient material again applied to wet the plants thoroughly.

The plots to which the treatments were applied again measured 2 × 10 m, and they were laid out in a randomized block design with three blocks, each containing one replicate of each treatment.

The effect on plant mortality was again determined by excavating the root system of a sample of 20 plants from each treatment plot, identified as previously. This was done on 27 August 1986.

Seeds were collected from the same 20 plants during the seeding period, twice weekly at first and then weekly. The seeds from each plot were bulked and separated from their pappuses and from corollas and other material in the sample by gently rubbing through a sieve and gentle winnowing. The seeds from each plot were then weighed air dry, and their germination tested as previously.

Seedlings from all seeds which germinated were planted out into soil in seed trays to see if there was any effect of the herbicide treatments on seedling establishment. The trays were kept moist in an unheated glasshouse from early June to mid October, when the number of surviving seedlings were counted.

Similar analyses to those used in Trial 1 were applied to the data from this trial.

Trial 3

This trial was carried out in the summer of 1984–85 on a dairy pasture that had been boom sprayed with 2,4-D in May 1983 for ragwort control. The ragwort population again consisted of large multi-stemmed flowering plants developed from plants not killed by the previous boom spraying. The pasture was dominated by *Lolium perenne* and *Trifolium repens*.

Herbicides were applied as spot sprays on 5 February, at the time the first flowers were beginning to turn brown. Clopyralid was applied at two rates, 0.3 and 0.6 g l^{-1} in combination with diquat at 2.0 g l^{-1} plus a surfactant. The standard treatment, 2,4-D as the iso-octyl ester at 2.4 g l^{-1} in combination with diquat at 2.0 g l^{-1} plus surfactant, was again included for comparison, and there was an unsprayed control. The spraying equipment and technique were as used previously.

The treatments were again applied to ragwort plants in plots laid out in a randomized block design. The plots measured 10 × 30 m in this trial. Three blocks were used, with one replicate per block.

The effects of the herbicide treatments on plant mortality were determined as before, on 28 August 1985, again using a sample of 20 plants. Seeds were collected from the 20 sample plants in each plot on 26 February, and tested for germinability as previously.

Results

Trial 1

Plant mortality All herbicide treatments applied to rosettes and shooting plants severely suppressed top growth and completely prevented flowering. In the period to the end of March, mortality of the top growth in plants sprayed at these growth stages showed a highly significant response ($P < 0.001$) to increasing rate of clopyralid (Table 1*a*). Herbicide treatments with diquat applied to flowering plants caused rapid destruction of the top growth in all but a small number of plants (Table 1*a*). For plants sprayed with clopyralid alone at flowering, mortality of the top growth was first observed in May, when there was a highly significant response ($P < 0.001$) to increasing rate of clopyralid (Table 1*a*).

Plants with living top growth in May included those showing regrowth as well as those with shoots persisting from the time of spraying. Plants with living top growth in August were all showing vegetative regrowth from the crown and/or roots. These plants, together with a greater number of plants from some treatments without any top growth but with living roots in August (Table 1*b*) had formed callus tissue between the living and dead crown or root, and would have been expected to recover fully and establish new plants (Cairns 1938).

All herbicide treatments, except clopyralid applied alone at 0.3 g l^{-1} at flowering, significantly reduced ($P < 0.001$) the number of plants surviving in August compared with the control (Table 1*b*). There were no consistent differences between the clopyralid treatments and the standard 2,4-D ester treatments in the effects on plant mortality.

Seed production and germinability Seed production of flowering plants was completely prevented by the use of herbicide mixtures containing diquat (Table 2*a*), whereas more than half the plants treated with clopyralid alone produced seeds. There was no effect of rate of application of clopyralid on the number of plants producing seeds. The quantity of seeds produced was greatly reduced compared with unsprayed plants, although this was not measured in this trial.

Seeds from plants treated with clopyralid showed reduced germinability compared with untreated plants, especially in the case of later maturing seeds (Table 2*b*). Differences in germinability between the three rates of clopyralid were not significant ($P > 0.05$). Many seedlings from the

Table 2 Trial 1: effect of herbicide treatments applied at flowering on seed production and germinability of ragwort seeds

(*a*) Number of plants producing seeds out of 20 plants observed (means of eight replicates for control and 2,4-D plus diquat treatments; means of four replicates for clopyralid treatments)

	Herbicide treatment[A]					
Control	E + D	C 0.3 + D	C 0.6 + D	C 0.3	C 0.6	C 1.2
20	0	0	0	11	12	12

[A]See footnote for Table 1*a*.

(*b*) Germinability of ragwort seeds collected on two occasions following treatment (mean percentage germination of two lots of 100 seeds collected from eight replicates of the control and four replicates of the clopyralid treatments on each occasion)

		Herbicide treatment[A]		
Date collected	Control	C 0.3	C 0.6	C 1.2
28.ii.84	81	59	44	45
19.iii.84	85	24	10	13

[A]See footnote for Table 1*a*.

Levels of significance of the treatment effects

Source of variation	
Collection date	$P < 0.001$
Control *v*. herbicide	$P < 0.001$
Between herbicides	$0.05 < P < 0.1$
Collection date × (control *v*. herbicide)	$P < 0.001$
Collection date × herbicide	n.s.

clopyralid treatments were glassy in appearance, with short stubby roots, which suggested that their subsequent establishment could be affected. Seeds remaining un-germinated after 14 days were either barren or soft and were therefore considered non-viable.

Trial 2

Plant mortality Whereas 2,4-D caused an increase in plant mortality compared with the control, clopyralid either had no effect, as at the pre-flowering stage, or the effect of reducing mortality, as at the two later stages (Table 3). Many plants treated with clopyralid at flowering and pre-seeding produced a second crop of flowers, and plants surviving to August 1986 were mostly showing vegetative regrowth from the crown. All plants with living roots at this time would have been expected to recover.

No plants from the standard treatment, 2,4-D plus diquat, survived to August.

Seed production, germinability, and seedling establishment As in the first trial, for the complete prevention of seed production at flowering it was necessary to use diquat (Table 4*a*). Clopyralid prevented seed production only when applied at the pre-flowering stage. 2,4-D used alone was less effective than clopyralid, but also prevented seed production in more than half the observed plants treated at pre-flowering.

For both herbicides the quantity of seed produced increased significantly ($P < 0.001$) as the time of application was delayed (Table 4*b*). For clopyralid, but not 2,4-D, there was also a significant increase ($P < 0.001$) in germinability with delay in the time of application (Table 4*c*). Seeds remaining ungerminated were again considered non-viable.

Although many seedlings from both the clopyralid and 2,4-D treatments were again abnormal in appearance, there were no significant effects ($P > 0.05$) of either herbicide on establishment of seedlings planted out following germination (Table 4*d*). Seedlings varied in size from 10 mm in diameter with 4 leaves, to 80 mm in diameter with 10 leaves, but there was a complete range of sizes from all treatments, with no apparent difference between treatments in the distribution of seedlings between the different sizes.

Trial 3

Plant mortality All herbicide treatments had a similar effect in causing very high levels of plant mortality in comparison with the control (Table 5).

Seed germinability Small quantities of seeds were collected from the treated plants but germinability was extremely low, with all herbicide treatments having a similar effect (Table 6).

Discussion

The excellent results obtained in the control of ragwort with clopyralid applied to

Table 3 Trial 2: effect of the herbicide treatments applied at three times during the flowering period on mortality of ragwort plants

Number of plants with living roots out of 20 plants observed on 27.viii.86 (means of three replicates)

Control	Herbicide treatment[A] Pre-flowering		Flowering			Pre-seeding	
	E	C 0.6	E + D	E	C 0.6	E	C 0.6
3.0	0.7	3.0	0	0	10.0	0	5.7

[A]See footnote for Table 1*a*.

Levels of significance of the treatment effects

Source of variation	
Control *v.* herbicide	n.s.
Between herbicides	$P < 0.001$
Clopyralid *v.* time of application	$P < 0.01$
2,4-D *v.* time of application	n.s.

Table 4 Trial 2: effect of the herbicide treatments applied at three times during the flowering period on seed production and germinability of ragwort seeds, and their subsequent establishment as transplanted seedlings

(*a*) Number of plants producing seeds out of 20 plants observed (means of three replicates)

Control	Herbicide treatment[A] Pre-flowering		Flowering			Pre-seeding	
	E	C 0.6	E+ D	E	C 0.6	E	C 0.6
20	9	0	0	20	19	20	20

[A]See footnote for Table 1*a*.

Levels of significance of the treatment effects

Source of variation	
Control *v.* herbicide	$P < 0.01$
Between herbicides	$P < 0.001$
Clopyralid *v.* time of application	$P < 0.001$
2,4-D *v.* time of application	$P < 0.01$

(*b*) Seed production, g plant^{-1}, from plants which produced seeds out of 20 plants observed (means of three replicates)

Control	Herbicide treatment[A] Pre-flowering		Flowering			Pre-seeding	
	E	C 0.6	E + D	E	C 0.6	E	C 0.6
3.24	0.14	–	–	0.85	0.33	2.51	1.79

[A]See footnote for Table 1*a*.

Levels of significance of the treatment effects

Source of variation	
Control *v.* herbicide	$P < 0.001$
Between herbicides	n.s.
Clopyralid *v.* time of application	$P < 0.001$
2,4-D *v.* time of application	$P < 0.001$

Table 4 (*c*) Germinability of ragwort seeds (mean percentage germination of two lots of 100 seeds collected from three replicates)

Control	Herbicide treatment[A]						
	Pre-flowering		Flowering			Pre-seeding	
	E	C 0.6	E + D	E	C 0.6	E	C 0.6
92	55	–	–	63	20	65	65

[A]See footnote for Table 1*a*.

Levels of significance of the treatment effects

Source of variation	
Control *v*. herbicide	$P < 0.001$
Between herbicides	$P < 0.01$
Clopyralid *v*. time of application	$P < 0.001$
2,4-D *v*. time of application	n.s.

(*d* Establishment of transplanted ragwort seedlings (mean % survival after approximately 4.5 months of seedlings from two lots of 100 seeds collected from three replicates)

Control	Herbicide treatment[A]						
	Pre-flowering		Flowering			Pre-seeding	
	E	C 0.6	E+D	E	C 0.6	E	C 0.6
78	64	–	–	83	59	67	49

[A]See footnote for Table 1*a*.

Levels of significance of the treatment effects

Source of variation	
Control *v*. herbicide	n.s.
Between herbicides	n.s.
Clopyralid *v*. time of application	n.s.
2,4-D *v*. time of application	n.s.

Table 5 Trial 3: effect of the herbicide treatments applied at flowering on mortality of ragwort plants
Number of plants with living roots out of 20 plants observed on 28.viii.85 (means of three replicates)

Control	Herbicide treatment[A]		
	E + D	C 0.3 + D	C 0.6 + D
12.0	0.3	0.3	0

[A]See footnote for Table 1*a*.

Table 6 Trial 3: effect of the herbicide treatments applied at flowering on the germinability of ragwort seeds
Mean percentage germination of four lots of 100 seeds collected from three replicates

Control	Herbicide treatment[A]		
	E + D	C 0.3 + D	C 0.6 + D
87	0	0.5	0.5

[A]See footnote for Table 1*a*.

late rosette and shooting plants indicate that this material has to be considered as a possible alternative to 2,4-D for spot treatment at these stages of growth. In work elsewhere (Naish 1975; Richards *et al.* 1983) clopyralid applied as a boom spray at the rosette stage gave effective control of ragwort at rates down to 0.2 kg ha^{-1} when used alone, or down to 0.1 kg ha^{-1} in mixtures with 2,4-D and triclopyr. However, the sensitivity of clover to clopyralid makes it unsuitable for boom application in most pasture situations. At the lowest rate tested, 0.3 g l^{-1}, clopyralid is currently slightly cheaper than 2,4-D ester at 4 g l^{-1}.

At the flowering stage clopyralid on its own failed to prevent the production of viable seeds at the rates used in these trials. Since prevention of viable seed production is the main aim of spraying at flowering, the use of clopyralid on its own at this stage of growth cannot be recommended.

Although the abnormal appearance of seedlings from seeds produced by plants sprayed with clopyralid at flowering suggested that establishment of these seedlings may be very low compared with seedlings from unsprayed plants, this was not observed in the second trial under the conditions used to test establishment. These conditions would be considered very favourable for establishment. In the field, where conditions for seedling establishment may not be so favourable due to competition from other plants and environmental stress (e.g. cold, moisture) reduced establishment of these seedlings would be expected. Notwithstanding this, establishment in the field of some seedlings from plants treated with clopyralid at flowering could not be ruled out.

Ragwort is well known for its ability to recover from damage at the flowering stage, whether due to slashing, grazing or herbicides (Poole and Cairns 1940; Harper 1958). Significant regrowth occurred in the first trial only with clopyralid at 0.3 g l^{-1}, but occurred in the second trial with clopyralid at 0.6 g l^{-1}.

The results from the first two trials indicate that when spraying is delayed until the flowering stage it is necessary to use diquat to prevent seed production. The excellent results obtained with diquat in combination with either 2,4-D or clopyralid in all trials contrast with the poor results obtained in some instances by farmers using 2,4-D and diquat at flowering (Friend, personal observations). Poor results may be expected when spraying is carried out in hot, dry conditions, when the plants may be under moisture stress. Thorough coverage of the inflorescences, foliage and stems right to ground level is also important for maximum effect of diquat.

For the complete prevention of viable seed production spraying must be carried out in early flowering, before the first flowers begin to turn brown.

The results indicate that clopyralid may be considered as an alternative to 2,4-D for use as a spot spray on ragwort at the late rosette and shooting stages of growth. The results from the second trial suggest that clopyralid could be used right up to the flowering stage, while the first flowers are still in bud, whereas 2,4-D needs to be applied at an earlier stage during shooting to prevent the formation of viable seeds.

Further trials are necessary to show that the new herbicide can be relied on to perform consistently in achieving high levels of control of ragwort in different situations. Such trials are currently being carried out in Tasmania. Should it prove to be more reliable than 2,4-D, its adoption in place of 2,4-D could be recommended. Otherwise, its adoption will be influenced by the continued availability of 2,4-D and the relative cost of the two herbicides in the future.

Acknowledgments

Sites for the trials were generously provided by K. G. Briggs of Golden Valley and D. E. Tracey of Weegena.

Assistance in the field by P. L. Dolan and R. DeCesare is gratefully acknowledged. The experimental design and statistical analyses were carried out by S. P. Wallace and T. B. Koen.

References

Anon. (1985). 'Ragwort (*Senecio jacobaea*): Declared Secondary Weed'. (Tasmanian Department of Agriculture. Leaflet AW2.)

Backstrom, J. (1978). The phenoxy acid problem in Sweden. *Ecological Bulletins* (Stockholm) **27**, 108-21.

Cairns, D. (1938). Vegetative propagation in ragwort. *New Zealand Journal of Science and Technology* **20**, 173A-83A.

Fricke, E. F. (1944). Ragwort. *Tasmanian Journal of Agriculture* **15**, 1-9.

Haagsma, T. (1975). Dowco 290 herbicide—a coming new selective herbicide. *Down to Earth* **30**, 1-2.

Harper, J. L. (1958). The ecology of ragwort (*Senecio jacobaea*) with especial reference to control. *Herbage Abstracts* **28**, 151-7.

Hartley, W. (1979). 'A Checklist of Economic Plants in Australia'. (CSIRO: Melbourne.)

Hoar, S. K., Blair, A., Holmes, F. F., Boysen, C. D., Robel, R., Hoover, R., and Fraumeni, J. F. (1986). *JAMA: The Journal of the American Medical Association* **256**, 1141-7.

Makepeace, W., and Thompson, A. (1982). Ragwort control using a rope wick applicator. *Proceedings of the 35th New Zealand Weed and Pest Control Conference*, 256-9.

McCullagh, P., and Nelder, J. A. (1983). 'Generalized Linear Models'. (Chapman and Hall: London.)

Naish, R. W. (1975). Dowco 290—a new growth regulator herbicide. *Proceedings of the 28th New Zealand Weed and Pest Control Conference*, 177-80.

Pemberton, J. M. (1979). 2,4-D and 2,4,5-T: reasons for comfort and concern. *Journal of the Australian Institute of Agricultural Science* **45**, 165-8.

Poole, A. L., and Cairns, D. (1940). Botanical aspects of ragwort (*Senecio jacobaea* L.) control. *Bulletin of the New Zealand Department of Scientific and Industrial Research* **82**, 1-61.

Richards, M. C., Swift, G., Cleland, A. T., and Davies, D. H. K. (1983). Evaluation of 2,6-dichloropicolinic acid, triclopyr, 2,4-D ester and MCPA, alone and in mixtures, for *Senecio jacobaea* control in grassland. *Annals of Applied Biology* **102** (Supplement, Tests of Agrochemicals and Cultivars, A), 104-5.

Schmidl, L. (1972). Biology and control of ragwort, *Senecio jacobaea* L., in Victoria, Australia. *Weed Research* **12**, 37-45.

Severson, D. (1980). The politics of 2,4-D. *Wheat Grower* **3** (7), 16-8.

Thompson, A. (1974). Herbicide effects on ragwort and pasture. *Proceedings of the 27th New Zealand Weed and Pest Control Conference*, 90-3.

Thompson, A. (1977). Herbicides for spot treatment of ragwort in pasture. *Proceedings of the 30th New Zealand Weed and Pest Control Conference*, 34-7.

Thompson, A. (1983). Pasture weed control by rope wick applicator. *Proceedings of the 36th New Zealand Weed and Pest Control Conference*, 96-8.

Watt, T. A. (1987). The biology and toxicity of ragwort (*Senecio jacobaea* L.) and its herbicidal and biological control. *Herbage Abstracts* **57**, 1-16.