Research reports

Chemical control of saffron thistle (*Carthamus lanatus* L.) in pasture in the South Australian Mallee.

G.M. Fromm, Plant Protection Agronomist, Department of Agriculture, Murray Bridge, South Australia 5253, Australia.

Summary

Several herbicide treatments were evaluated for the control of, or the reduction in normal seed head development of, saffron thistle (*Carthamus lanatus* L.) in pasture in the South Australian Mallee.

Paraquat at 100 g a.i. ha^{-1} applied either alone, or as a proprietary mixture with diquat or amitrole, effectively controlled saffron thistle at the stem elongation stage when the majority of plants were between 12 cm and 50 cm high. Higher rates were needed to obtain acceptable control when applied at the rosette and flowering stages. Glyphosate at 162 g a.i. ha^{-1} was not as effective as paraquat at 100 g a.i. ha^{-1} when applied at the rosette or stem elongation stage. Applications to saffron thistle rosettes of paraquat at 400 g a.i. ha^{-1} applied alone and 375 g a.i. ha^{-1} applied as a proprietary mixture with diquat, and glyphosate at 324 g a.i. ha^{-1} gave effective control. When applied to flowering saffron thistle paraquat at 200 g a.i. ha^{-1} applied alone or at 125 g a.i. ha^{-1} applied as a proprietary mixture with diquat, and glyphosate at 216 g and 270 g a.i. ha^{-1} were the most effective treatments in reducing the number of normal seed heads formed. Saffron thistle plants which survived the glyphosate treatments applied at stem elongation or flowering stage developed seed heads in the leaf axils of the main stem and subsequently still set some seed.

Introduction

Carthamus lanatus L. (saffron thistle, false star thistle, woolly star thistle) is an autumn to early spring germinating erect annual, growing to one metre or more in height. The main stem of the mature plant is rigid and usually branched at the top with solitary flower heads carried terminally on the main stem and branches. The stem leaves are rigid and deeply divided with each lobe terminating in a short spine. The leaf-like bracts surrounding each flower head are also rigid with sharp spines.

Although saffron thistle has little fodder value sheep will eat the plant when young and when the flowering stem is emerging from the rosette (Parsons, 1973). However, once the plant has matured it is not grazed because of the sharp spines on the leaves and bracts. Stock are reluctant to graze areas where saffron thistle plant numbers are high and potentially useful pasture is left ungrazed. Severe mouth and eye injuries can be caused by the spines if stock are forced to graze amongst dense patches of the plant. In addition, saffron thistle is a problem in cereal crops where it competes with the cereals and, if not controlled, can contaminate grain. In 1988/89 the Australian Wheat Board standards for saffron thistle whole seeds or their equivalent in pieces per half litre of wheat ranged from five for category Australian Hard to 50 for category Australian Feed and samples exceeding those standards were downgraded.

Current control methods aim to contain the plant and exhaust seed reserves in the soil by using a combination of cultivation, slashing and herbicides in conjunction with crops and pasture (Anon, 1978). The use of selective herbicides has generally been confined to the cropping phase of a rotation with most control methods in pasture being non-selective. Quinlivan and Pierce (1969) reported that saffron thistle seed can germinate over a period of seven years, although in Western Australia most germinates in the first two years. It is therefore important to prevent seed set over several years in both the pasture and cropping phases of a rotation.

Field observations have indicated that paraquat at 100 g[A] [as Gramoxone W®] and glyphosate at 108 g to 162 g [as Roundup®] could be used to either reduce the seed set, or give some control, of saffron thistle in pasture. Both products are registered in South Australia for use in pasture to reduce viable seed set of some annual grasses and broadleaf weeds. Initial experiments were established in 1984 to evaluate the effect of these and other herbicides on seedhead development when applied to saffron thistle at the flowering stage.

Footnote:

[A] Herbicide rates are expressed as g a.i. ha^{-1}.

Subsequent experiments in 1985 were established to evaluate several herbicides applied prior to flowering for the control of saffron thistle. In the South Australian Mallee saffron thistle is often found growing in pastures in association with onion weed (*Asphodelus fistulosus* L.) and experiments in 1986 and 1987 examined the effect of several herbicides applied either alone or as tank mixes to control both plants. This paper reports on the control of saffron thistle in the six experiments carried out from 1984 to 1987.

Materials and Methods

The experimental design used was a randomized complete block with three replicates. In experiments 1, 3 and 4 the plots were 4.62 x 40 m and in experiments 2, 5 and 6 the plots were 2.97 x 40 m, 4 x 40 m and 4 x 35 m respectively. Herbicides were applied with a trailer mounted hydraulic boomsprayer fitted with stainless steel Spraying Systems flat fan tee jet nozzles. In experiments 1 to 4 the nozzle size was 8001 with a nozzle spacing of 33 cm and in experiments 5 and 6 the nozzle size was 110015 with a nozzle spacing of 50 cm. The unit was pressurized by carbon dioxide and maintained an operating pressure of 220 kPa, giving an application rate of between 61 and 86.9 L ha^{-1}, depending on nozzle size and the ground speed of the vehicle towing the unit. Dates of application, application rates, boom height above ground level and the growth stage and size of saffron thistle at the time of application are given in Table 1.

The method used for assessing herbicidal efficacy varied depending on the objective of the experiment. In experiment 1, treatment effects on terminal seedheads were measured 118 days after treatments were applied (DAT). Ten seedheads per plot were selected randomly and visually assessed on structural appearance and seed normality. The external appearance of these seedheads was then used as a reference when counting the number of visually normal terminal seedheads on the main stem and branches of 10 plants selected randomly at approximately three metre intervals in that plot. In addition the seedheads from 15 plants (five large, five average and five small plants) selected randomly in each plot were hand harvested. The seedheads from the same treatments in each of the three replicates were then bulked. The heads were threshed and the seed weight from the 45 plants for each treatment recorded. In experiment 2 the treatment effects were measured 90 DAT. The assessment method was the same as that used in experiment 1 except that no seedheads were harvested.

In experiment 3 the treatment effects were assessed visually 87 DAT by comparing the number of dead plants with the number of living plants in each plot. In experiment 4 the number of dead and living plants were

Table 1. Details of sites at the time of application

Experiment number	Date treatments applied	Spray mixture application rate(L ha^{-1})	Boom height above ground (cm)	Growth stage and size of saffron thistle
1	6 November 1984	86.9	85	Early flowering (seed head on main stem flowering), 25-85 cm in height, majority 45-55 cm.
2	5 December 1984	72.8	105	Full flowering (seed heads on main stem and branches flowering), 35-110 cm in height, majority 70-80 cm.
3	4 October 1985	61.0	70	Stem elongation, 7-27 cm in height, majority 14-17 cm.
4	31 October 1985	67.0	95	Stem elongation, 5-70 cm in height, majority 30-55 cm, plants 50 cm or more in height starting to branch and form seedheads.
5	10 September 1986	68.9	70	Seedling 4-6 leaf to rosettes 7-15 cm in diameter, majority at rosette stage 10-15 cm in diameter with 14-18 leaves.
6	29 October 1987	68.4	75	Stem elongation, 5-75 cm in height, majority 12-35 cm. Plants 50 cm or more in height starting to branch and form seedheads.

counted 61 DAT in five 0.36 m^2 quadrats at approximately seven metre intervals in each plot, and the percentage control was then determined. In experiment 5 the herbicide effects were assessed visually 132 DAT by comparing the number of dead plants with the number of living plants in each plot. In experiment 6 living plants were counted 81 DAT in seven 0.33 m^2 quadrats at approximately four metre intervals in each plot. Percentage control was determined by comparing the number of living plants in each treatment with the number of living plants in the unsprayed plot in that replicate.

Results

Experiments 1 and 2

The data from these experiments were analysed by analysis of variance and Tukey's H.S.D. No transformation of the data was necessary since the residual variance was relatively homogeneous (Table 2).

All treatments except paraquat at 60 g in experiment 1, significantly ($P<0.05$) reduced the number of visually normal terminal seedheads. In experiment 1, glyphosate at 216 g, 162 g and 108 g and paraquat at 150 g were the most effective treatments, both in the reduction of normal terminal seedheads on the main stem and branches, and in the reduced amount of seed harvested from 45 plants. In experiment 2, paraquat/diquat at 125 g/75 g [as Spray Seed®], paraquat at 200 g, paraquat/amitrole at 125 g/250 g [as Pre-Ceed®] and glyphosate at 270 g were the most effective treatments. However, observations at both sites showed that glyphosate, at all rates, whilst reducing the number of normal terminal seedheads, did not kill all the plants. On the surviving plants, up to 15 small seedheads developed in the leaf axils with each containing visually normal seeds. The number of surviving plants ranged from 10% to 50%, with the larger plants surviving especially at the lower rates of glyphosate. The addition of 2,4-D diamine, an oil based amine formulation of 2,4-D [as Dacamine 4D®] to paraquat/amitrole reduced the control obtained when compared to paraquat/amitrole applied alone at the same rate. Overall, the results from these treatments applied at early to full flowering, were considered to be unsatisfactory in reducing normal seedhead numbers.

Table 2. Experiments 1 and 2: Effect of herbicides applied at flowering on normal seed head development of saffron thistle

Herbicide	Rate (g a.i .ha^{-1})	Experiment 1: Number of normal seed heads per 10 plants	Experiment 1: Seed weight from 45 plants (g per treatment)	Experiment 2: Number of normal seed heads per 10 plants
paraquat	60	111.3	54.3	173.7
paraquat	80	91.0	51.9	116.0
paraquat	100	41.3	26.3	124.7
paraquat	150	27.0	25.8	
paraquat	200			67.3
glyphosate	108	28.7	2.7	197.7
glyphosate	162	16.7	6.3	204.3
glyphosate	216	4.3	0.6	
glyphosate	270			87.7
paraquat/diquat	125/75			56.3
paraquat/amitrole	81/163			109.3
paraquat/amitrole	125/250			82.3
paraquat/amitrole +2,4-D amine	81/163 +120			127.3
unsprayed		132.3	105.4	295.0
Tukey's h.s.d. ($P<0.05$)		23.7	n.a.[A]	78.9

[A] data not analysed

Experiments 3 and 4

The data from these experiments were analysed by analysis of variance and Tukey's H.S.D. using arcsine and square root transformations where appropriate (Table 3).

In these experiments herbicides were applied at stem elongation. Treatments which gave either a 94% or greater reduction in the number of, and/or a residual population of five or less, living saffron thistle plants m^{-2} were considered to have given effective control of saffron thistle. Field observations indicated that stock would graze amongst the remaining live plants. In experiment 3, paraquat at 80 g, with the addition of spraying oil, and at 100 g, either alone or as a proprietary mixture with diquat, achieved acceptable control of saffron thistle while paraquat at 60 g with or without the addition of spraying oil and at 80 g without the addition of spraying oil, glyphosate at 108 g to 216 g, and the proprietary mixtures of paraquat/diquat at 80 g/48 g and paraquat/amitrole at 80 g/160 g and 100 g/200 g, did not adequately control the plant. The addition of spraying oil at 2% v/v to the spray mixture with paraquat at all rates tested in this experiment marginally improved the control obtained.

In experiment 4 paraquat at 80 g with the addition of 2% v/v spraying oil to the mixture, paraquat at 100 g to 140 g either with or without the addition of spraying oil, glyphosate at 216 g, paraquat/diquat at 80 g/48 g or more

Table 3. Experiments 3 and 4: Effect of herbicides applied at stem elongation on saffron thistle

Herbicide	Rate (g a.i. ha^{-1})	Experiment 3	Experiment 4	
		Percentage control	Live saffron thistle plants m^{-2}	Percentage control
paraquat	60	88 (1.224)[C]		
paraquat + oil[A]	60	93 (1.316)		
paraquat	80	90 (1.256)	7.0 (2.773)[D]	90 (1.254)[C]
paraquat + oil	80	94 (1.344)	3.0 (1.856)	96 (1.377)
paraquat	100	96 (1.383)	2.0 (1.723)	96 (1.381)
paraquat + oil	100	96 (1.397)	1.5 (1.558)	97 (1.407)
paraquat	120		0.9 (1.384)	98 (1.439)
paraquat + oil	120		0.6 (1.247)	99 (1.460)
paraquat	140		1.7 (1.572)	97 (1.434)
paraquat + oil	140		1.7 (1.572)	97 (1.439)
glyphosate[B]	108	48 (0.769)	23.7 (4.891)	67 (0.962)
glyphosate[B]	162	80 (1.114)	9.4 (3.141)	88 (1.230)
glyphosate[B]	216	90 (1.276)	5.0 (2.448)	94 (1.323)
paraquat/diquat	80/48	90 (1.256)	3.3 (2.055)	95 (1.342)
paraquat/diquat	100/60	97 (1.401)	1.3 (1.504)	98 (1.416)
paraquat/diquat	120/72		0.7 (1.316)	99 (1.460)
diquat	100		17.4 (4.255)	74 (1.030)
diquat	144		9.1 (3.131)	77 (1.079)
paraquat/amitrole	80/160	85 (1.176)	3.7 (2.166)	94 (1.327)
paraquat/amitrole	100/200	87 (1.198)	0.6 (1.233)	99 (1.492)
paraquat/amitrole	120/240		0.4 (1.151)	99 (1.521)
unsprayed		0 (0)	77.0 (8.788)	0 (0)
Tukey's h.s.d. ($P<0.05$)		(0.236)	(1.61)	(0.235)

[A] spraying oil [Ampol D-C-Tron®] added at 2% v/v to the spray mixture
[B] nonyl phenol ethylene oxide condensate nonionic surfactant [as Agral 600®] added at rate of 180 g a.i. 100 L water^{-1}
[C] values in parentheses are arcsine $\sqrt{(x/100)}$ transformations
[D] values in parentheses are $\sqrt{(x + 1)}$ transformations.

and paraquat/amitrole at 80 g/160 g or more effectively controlled saffron thistle. Although significantly reducing the number of living saffron thistle plants m^{-2}, paraquat at 80 g without oil, glyphosate at 108 g and 162 g and diquat at 100 g and 144 g [as Reglone®] did not give acceptable control. The addition of 2% v/v spraying oil to the spray mixture with paraquat at all rates tested in this experiment marginally improved the saffron thistle control obtained.

Experiments 5 and 6

The data from these experiments were analysed by analysis of variance and Tukey's H.S.D using arcsine and square root transformations where appropriate (Table 4).

In experiment 5 the treatments were applied at the seedling to rosette stage of saffron thistle. Paraquat at 400 g, glyphosate at 324 g and 648 g, paraquat/diquat at 375 g/225 g and paraquat at 200 g plus chlorsulfuron at 15 g [as Glean®] applied as a tank mixture effectively controlled 94% or more of the saffron thistle plants. The addition of 2,4-D amine at 500 g [as Nufarm Amicide 500®] to either paraquat or paraquat/diquat resulted in a reduction in the control achieved when compared to paraquat or paraquat/diquat applied alone at the same rate.

In experiment 6 treatments were applied at stem elongation. All treatments except glyphosate at 162 g, with or without the addition of 1% v/v spraying oil to the spray mixture, and glyphosate at 162 g plus metsulfuron methyl at 1.8 g [as Ally®] applied as a tank mixture with or without the addition of oil, effectively controlled 94% or more of the saffron thistle plants. The addition of 1% v/v spraying oil to the spray mixture with paraquat at 100 g and 200 g marginally improved control. However, when added to glyphosate at 162 g, paraquat/diquat at 94 g/56 g and glyphosate at 162 g plus metsulfuron methyl at 1.8 g the control obtained was reduced.

When chlorsulfuron was added to paraquat in experiments 5 and 6 and metsulfuron methyl was added to paraquat in experiment 5 and to paraquat, glyphosate or 2,4-D amine in experiment 6 the control was greater than that obtained by those products applied alone at the same rates.

Discussion

The results indicate that paraquat at 100 g can be used to effectively control saffron thistle in pasture when applied to plants at the stem elongation stage. However this rate, when applied either later to plants at the flowering stage or earlier when the majority of the plants were at the rosette stage, whilst significantly reducing normal seedhead numbers or controlling 80% of the plants respectively, did not give acceptable control of saffron thistle. Similar results have since been recorded on Eyre Peninsula (Dickinson, personal communication) and in other areas of South Australia (Luck, personal communication).

Glyphosate at 162 g did not give acceptable control of saffron thistle when applied to plants at the stem elongation stage in experiments 3, 4 and 6 or to rosettes in experiment 5. At 216 g it was the most effective treatment in reducing normal seedhead and seed development in experiment 1 but the control obtained was not acceptable. However, when applied at 216 g and 324 g or more to saffron thistle at the stem elongation or rosette stage in experiments 4 and 5 respectively glyphosate gave acceptable control but these rates are higher than those registered for use in pasture to reduce viable seed set of some annual grasses and broadleaf weeds. When applied at stem elongation stage, or later, surviving plants developed seedheads in the leaf axils of the main stems and to a lesser extent on the branches.

Where sheep grazed the pasture after treatment it was observed that the breakdown of saffron thistle plants, which in turn allowed easier stock access to pasture, was more rapid in plots treated with paraquat (alone or as a proprietary mixture with either diquat or amitrole) than in plots treated with glyphosate.

The results obtained when paraquat was applied as a proprietary mixture with diquat or amitrole were equivalent to, or only marginally better than, those obtained when paraquat was used alone at the same rate (a.i. ha^{-1}), suggesting that the use of these mixtures is only warranted, on a cost basis, if they are going to control plants other than those controlled by paraquat alone.

The addition of spraying oil at 1% v/v or 2% v/v to the spray mixture with paraquat marginally improved control. However, when added to paraquat/diquat at 94 g/56 g the control was marginally less than that obtained when oil was not added. When 1% v/v spraying oil was added to the spraying mixture with glyphosate alone, or glyphosate plus metsulfuron methyl, it produced a marginal reduction in control of saffron thistle.

Chlorsulfuron or metsulfuron methyl applied alone as post emergent treatments do not effectively control saffron thistle (Fromm, unpublished data). When added to paraquat, glyphosate or 2,4-D amine neither

Table 4. Experiments 5 and 6: Effect of herbicides and herbicide mixtures on saffron thistle

Herbicide	Rate (g a.i. ha^{-1})	Experiment 5	Experiment 6	
		Percentage control	Live saffron thistle plants m^{-2}	Percentage control
paraquat	100	80 (1.109)[C]	4.4 (2.254)[D]	94 (1.345)[C]
paraquat + oil[A]	100		2.1 (1.724)	97 (1.418)
paraquat	200	88 (1.224)	0.7 (1.307)	99 (1.477)
paraquat + oil	200		0.9 (1.341)	99 (1.486)
paraquat	400	99 (1.504)		
glyphosate	162	75 (1.069)	10.3 (3.283)	87 (1.212)
glyphosate + oil	162		21.6 (4.622)	73 (1.039)
glyphosate	324	98 (1.443)		
glyphosate	648	98 (1.443)		
paraquat/diquat	94/56	77 (1.070)	1.9 (1.670)	98 (1.421)
paraquat/diquat + oil	94/56		4.3 (2.111)	95 (1.388)
paraquat/diquat	188/113	93 (1.313)		
paraquat/diquat	375/225	98 (1.443)		
2,4-D amine	700	92 (1.281)	0.1 (1.065)	99 (1.547)
MCPA amine	700	73 (1.033)		
2,4-D ester	560	82 (1.138)		
paraquat + 2,4-D amine	100 + 700		1.4 (1.549)	98 (1.438)
paraquat + 2,4-D amine	200 + 500	80 (1.112)		
paraquat + chlorsulfuron[B]	100 + 15		2.7 (1.906)	97 (1.388)
paraquat + chlorsulfuron[B]	200 + 15	94 (1.341)		
paraquat + metsulfuron methyl[B]	100 + 4.2		1.3 (1.507)	98 (1.444)
paraquat + metsulfuron methyl[B]	200 + 4.2	93 (1.313)	0.4 (1.171)	99 (1.530)
paraquat + diuron	100 + 250		1.3 (1.401)	99 (1.500)
glyphosate + metsulfuron methyl[B]	162 + 1.8		8.3 (3.045)	90 (1.243)
glyphosate + metsulfuron methyl + oil	162 + 1.8		13.0 (3.654)	83 (1.160)
paraquat/diquat + 2,4-D amine	188/113 + 500	87 (1.209)		
2,4-D amine + metsulfuron methyl[B]	700 + 4.2		0.0 (1.000)	100 (1.571)
unsprayed		0(0)	79.3 (8.956)	0 (0)
Tukey's h.s.d. ($P<0.05$)		(0.297)	(1.677)	(0.240)

[A] spraying oil [Ampol D-C-Tron®] added at 1% v/v to the spray mixture
[B] nonyl phenol ethylene oxide condensate nonionic surfactant [as Agral 600®] added at rate of 120 g a.i. 100 L $water^{-1}$
[C] values in parentheses are arcsine $\sqrt{(x/100)}$ transformations
[D] values in parentheses are $\sqrt{(x + 1)}$ transformations.

reduced control compared to paraquat, glyphosate or 2,4-D amine applied alone at the same rates. However, chlorsulfuron and metsulfuron methyl effectively control medics (*Medicago* spp), a desirable component of mallee pastures and therefore treatments containing these products would not be used specifically for saffron thistle control.

A reduction in herbicidal efficacy was evident in experiments 2 and 5 when 2,4-D diamine was added to paraquat/amitrole and 2,4-D amine was added to paraquat and paraquat/diquat respectively when compared to paraquat/amitrole, paraquat and paraquat/diquat applied alone at the same rates. However, in experiment 6 a mixture of 2,4-D amine and paraquat gave marginally better control than paraquat and marginally worse control than 2,4-D amine applied alone at the same rates. Reduction in efficacy when the two products are tank-mixed has been observed in other work on different weeds (Fromm, unpublished data; Luck, personal communication).

The use of paraquat at 100 g appears to be a viable alternative to slashing as a control measure for saffron thistle in pasture. However, the optimum timing for saffron thistle control (at stem elongation) will generally be too late for the optimum time to prevent viable seed formation in annual grasses where the technique is known as spray topping. Further work is necessary to determine whether, when spraying at the optimum time for reducing grass seedset, the slight reduction in saffron thistle control is acceptable.

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