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Compendium of branched broomrape research

Section 11. Control - herbicides

A COMPILATION OF RESEARCH REPORTS FROM THE BRANCHED BROOMRAPE ERADICATION PROGRAM SOUTH AUSTRALIA

DECEMBER 2013

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

SOUTH AUSTRALIA

Government of South Australia
Primary Industries and Regions SA

Compendium of branched broomrape research

Information current as of 6 December 2013

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Table of Contents

1. Herbicide control of branched broomrape in host crops and pastures

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Animal and plant Control Commission

October 2000

Literature review

Low rates of post-emergent herbicides applied to host crops have been used successfully to control broomrapes (Table 1). Dhanapal et al. (1996), citing Jacobsohn and Levy 1986, listed vetch, faba bean, carrot, cabbage and celery as being tolerant to glyphosate, whilst tomato, eggplant and pea were very sensitive.

Table 1. Control of broomrape on crops with different herbicides summarised from literature.

Crop	Broomrape	Herbicide/s	Rate	Degree of control	Reference
faba bean	*O. crenata*	glyphosate + imazaquin	64 g ha^{-1} + 90 g ha^{-1}	effectively controlled	Zahran et al. 1988
sunflower	*O. cernua*	glyphosate	20-40 g ha^{-1} every 12-14 days	80%	Castejon-Munoz et al. 1990
broad bean field bean	*O. crenata*	glyphosate	60mL in 500L water /ha	almost completely eliminated	Halila 1988
Vicia faba	*O. crenata* and *O. aegyptica*	glyphosate + imazaquin	80 g ha^{-1} + 10 g ha^{-1}	100%	Sauerborn et al. 1989
sunflower	O. cernua	imazethapyr or imazapyr or chlorsulfuron	20-40 g ha^{-1} or 12.5-25 g ha^{-1} or 4-6 g ha^{-1}	efficiently without crop injury	Garcia-Torres et al. 1994
sunflower	O. cernua	imazapyr	10-15 g ha^{-1} at 12-19 leaves stage	effective	Garcia-Torres et al. 1995
sunflower	O. cernua	imazapyr	10 g ha^{-1} twice at 12-19 leaves stage, 10-14 days apart	effective	Garcia-Torres et al. 1995
faba bean	*O. crenata*	glyphosate	60 g ha^{-1} when tubercles first visible and again 2 weeks later	fully successful but 20% crop damage	Schmitt et al. 1979
carrot	*O. crenata*	glyphosate	50 g ha^{-1}	very successful	Jacobsohn and Levy 1986
celery	*O. aegyptica*	glyphosate	50 g ha^{-1}	very successful	Americanos 1991
cabbage		glyphosate			Americanos and Vouzounis 1992

Crop	Broomrape	Herbicide/s	Rate	Degree of control	Reference
faba bean		imazaquin	40 g ha^{-1} twice	more effective than glyphosate in Syria	Linke 1991
pea		imazaquin	20 g ha^{-1} twice	promising	Linke 1991
cabbage		glyphosate	60-100 g ha^{-1} twice	selective	Americanos and Vouzounis 1995
cabbage		imazaquin	5-10 g ha^{-1} as heads starting to form	selective	Americanos and Vouzounis 1995
faba bean		imazethapyr		selective	García -Torres and López-Granados 1991
pea		imazethapyr		selective	Jacobsohn and Eldar 1992
vetch	*O. aegyptica*	glyphosate	18 or 36 g ha^{-1} suggest 2×18 g ha^{-1}	no. attachments greatly reduced	Nandula et al. 1999
faba bean	*O. crenata*	glyphosate	34 g ha^{-1} at 60 and 75 days after planting + NPK fertiliser	88% reduction in flower spikes m^{-2}	Hussein et al. 1998
field tomato	*O. aegyptica*	chlorsulfuron	2.5 g ha^{-1} split over 3 applications 10-14 days apart with sprinkler irrigation	90% control	Hershenhorn et al. 1998
field tomato	*O. aegyptica*	triasulfuron	7.5 g ha^{-1} split over 3 applications 10-14 days apart with sprinkler irrigation	80% control	Hershenhorn et al. 1998
pot tomato	*O. aegyptica*	rimsulfuron	25 g ha^{-1} at 10, 20, and/or 30 days after trans?planting	Split application 10 & 20 gave 95% control. Split application 10, 20 & 30 gave 100% control.	Hershenhorn et al. 1998
faba bean	*O. crenata*	imazethapyr + imazapyr	seed treat + late post-em @ 5 g ha^{-1}	>95% control	Jurado-Exposito et al. 1997
tobacco	*O. cernua*	glyphosate	500 g ha^{-1} at 60 days after transplanting	75-80% control	Dhanapal 1996
tobacco	*O. cernua*	imazaquin	10 g ha^{-1} at 30 days after transplanting	75-80% control	Dhanapal 1996
field tomato	*O. aegyptica* and *O. ramosa*	glyphosate	30-50 g ha^{-1} twice	Very effective but reduced tomato yield	Vouzounis and Americanos 1998

Glyphosate is less effective if initial application is applied a little too late, after Orobanche shoot buds begun elongating. Also, if early sown faba bean then need two doses rather than one, three for very early sowing. (Mesa-García and Vasquex-Cobo 1985)

Faba bean - single dose glyphosate of 60 or 120 g ha^{-1} caused less than 5% yield reduction when applied at beginning of flowering. Double doses 120 g ha^{-1} and applications at vegetative stage more damaging. Mesa-García et al. 1984

Chlorsulfuron, triasulfuron and rimsulfuron damaged parasite organs and caused rapid death of Egyptian broomrape tubercles when applied after the parasite had completed attachment to host roots. (Hershenhorn et al. 1998)

Less effective treatments:

O. cernua and sunflowers - imazaquin (20-40 g ha^{-1}), trisulfuron (4 g ha^{-1}), primisulfuron (3 g ha^{-1}), acetochlor (4.4 kg ha^{-1}), metazachlor (2 kg ha^{-1}) (García -Torres et al. 1994)

Ineffective treatments:

O. cernua and sunflowers - imazamethabenz (200-600 g ha^{-1}), metochlor (3.3 kg ha^{-1}) (García -Torres et al. 1994)

O. crenata and faba bean - 2,4-D (Whitney 1973) - so expect Lontrel (clopyralid) which is also an auxin type herbicide to not be effective?

O. aegyptica/ramosa and tomato - trifluralin (Vouzounis and Americanos 1998)

Orobanche in potatoes - trifluralin, dinitramine, pendimethalin, oryzalin, oxadiazon (Kleifeld et al. 1982)

Materials and Methods

The site was a sand dune infestation where branched broomrape dried seed heads were located from the previous year. Plots were 15×30m and contained branched broomrape (approx. 0.2 m^{-2}). Resident weeds were onion weed, false caper, medic, capeweed, evening primrose, veldt grass, *Brassica tournefortii*, horehound, poached egg daisy, *Sonchus* sp., *Brachyscome*, and paddy melon. Plots were treated with glyphosate at 15mL/L on 10/5/00 and rotary hoed to 0.1m depth on 23/5/00. Grasses were controlled with Fusilade applied at the rate of 500 ml ha^{-1}.

The experiment comprised 12 treatments (Table 2) replicated four times. All herbicides were applied to plots twice, 6 weeks post-sowing of crops and 4 weeks later. Plots were sown in mid-June. All herbicides with the exception of gyphosate were applied at the label recommended rate. Pulse adjuvant was used with Spinnaker and Hasten adjuvant with On-Duty. An untreated control was included for all crops.

Field peas were sown at the rate of 150 kg ha^{-1}, canola at the rate of 4-6 kg ha^{-1}, vetch at 15-25 kg ha^{-1} and medic at 5 kg ha^{-1}. Peas and vetch were inoculated with Group E rhizobia and 5 kg ha^{-1} of nitrogen was applied. Canola plots received 20 kg ha^{-1} N. All plots received 20 kg ha^{-1} of phosphorous.

Plots were examined on 25 October 2000 and the number of broomrape plants in each plot were counted. Counts were also made of broomrape plants occurring in unsprayed areas adjacent to the plots.

Table 2. Herbicide experiment treatments

crop	herbicide	rate
Field pea cv Alma	Imazethapyr (Spinnaker)	48 g ai ha^{-1} (200 ml ha^{-1} product)
	glyphosate	20 g ai ha^{-1}
	Diflufenican (Brodal)	
	MCPA sodium	175 g ai ha-1 (700 ml ha-1 product
Vetch cv. Languedoc	Imazethapyr (Spinnaker)	20 g ai ha^{-1}
	glyphosate	20 g ai ha^{-1}
Canola cv. Mystic	glyphosate	20 g ai ha^{-1}
	Clopyralid (Lontrel)	45 g ai ha^{-1} (150 ml ha^{-1} product)
Canola cv. Clearfield	Imizapic + Imazapyr (On-Duty)	21 + 7 g ai ha^{-1} (40 ml ha^{-1} product)
Medic cv. Harbinger	Imazethapyr (Spinnaker)	48 g ai ha^{-1} (200 ml ha^{-1} product)
	glyphosate	20 g ai ha^{-1}
	MCPA amine	250 g ai ha^{-1} (500 ml ha^{-1} product)

Results and discussion

Very poor emergence of broomrape occurred in the plots or other areas of the site adjacent to plots. 14 broomrape plants were found with 3 of these in plots, 2 in control plots (field pea and Canola cv Mystic) and 1 broomrape plant in a glyphosate-treated vetch plot. The broomrape in the canola plot was hosting on *Brassica tournefortii*. As host testing has found that field pea is not a host it is assumed that the broomrape in this plot was also on a weed host.

Poor growth of crops may partly explain poor broomrape emergence across the plots. Crops were sown late and the cold soil temperatures may have resulted in poor growth and susceptibility to pests. Medic was the crop in the best condition but it was very sparse as it was not sown in high enough density. Other legumes and canola were in poor condition in untreated and treated plots, therefore it is not likely that poor condition was a result of herbicide application. Many of the peas were dead and canola and vetch plants showed signs of herbivory.

The results of this trial remain inconclusive. Poor broomrape emergence may have resulted from a number of factors. Poor host growth or lack of susceptibility of host crops to broomrape may explain the lack of infection in controls. Higher numbers of broomrape plants in the areas surrounding plots suggests that broomrape is hosting on weeds. The herbicides may have been effective in preventing weed growth in the plots and hence broomrape emergence. Alternatively, the herbicides may have successfully controlled broomrape on host crops but the trial results provide no evidence in support of this.

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2. Herbicide and cropping rotation trial relevant to the eradication of branched broomrape (*Orobanche ramosa*) in South Australia

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Report compiled by Jane Prider

Summary

This is a summary of the trial work on the herbicide and cropping system rotation trial conducted by John Matthews as part of a Grains Research and Development Commission (GRDC) funded project. The results have been compiled from reports in newsletters and presentations at the Thirteenth Australian Weeds Conference, Perth 2002 and the Fifteenth Australian Weeds Conference, Adelaide 2006. The main focus of the trial was to evaluate a number of management options including potential herbicides for the control of branched broomrape within cereal and host crops. The rotation trial was maintained over six years from 2001 – 2006. Plots were used until 2008 but herbicide application and crop choices reflected other priorities of the eradication program so are reported separately. Results from the rotation trial found that where group B herbicides had been used, broomrape emergence could be suppressed or even prevented in most years. Suitable group B herbicides were found for all crops in the cereal/canola/legume rotation. Glyphosate is also an effective herbicide that can provide a break in the group B cycle and can be used late in the growing season.

Introduction

Wheat and volunteer pasture is the preferred land use in the quarantine area. Barley or triticale can be substituted for wheat while crop legumes and canola have not been extensively grown. Cereals do not host broomrape although weeds in the crop and many components of the pasture can host the weed. As a starting point, trials test whether current herbicides and use patterns in wheat and pasture are effective for broomrape control. It is anticipated that control of hosts in wheat, although important for immediate crop quarantine status, will not lead to rapid decline of the seed bank.

An increased rate of decline might be achieved by establishing host crops and treating with effective herbicides at the appropriate time. Crops to be trialled include brassica species, canola, mustard, radish and legume species, vetch, peas and medic. Choice of crop has been limited to commercial crop types for potential income earning and availability of seed. Evaluation of herbicide rate and timings on potential host crops is important.

The trial was initially planned to run for three years with rotations of wheat, brassicas and legumes with a variety of other crops and herbicide treatments appropriate to the cropping area and sources from the literature for broomrape control. Crop rotations occurred over six years with all plots planted to pastures in the the following two years. Here we report the results of the initial five year rotation study.

Materials and methods

The trials were all conducted at the trial site at Mannum. This site has mallee sandy loam soils typical of the area infested by branched broomrape in South Australia. In 2001 a set of 6 replicate blocks was set up, each comprising 13 plots, 6 m by 20 m. Each plot was divided into a southern and northern section separated by a broad alleyway and each section was randomly assigned to be treated by herbicide or left as an untreated control (Fig 1). Crop choice and herbicide application rates were chosen for a typical mallee soil environment, i.e. 250-300 mm rainfall with a sandy loam alkaline soil.

REP 1	REP 2	REP 3
REP 1	REP 2	REP 3
REP 4	REP 5	REP 6
REP 4	REP 5	REP 6

Figure 1. Layout of replicate blocks at Mannum Trial Site. Each block was subdivided into 13 plots planted as described in Table 1. Treatments were applied to either the upper or lower portion of each plot in a replicate block. Each replicate plot was divided by an alleyway (shaded).

The trials included seven rotation types that had different herbicide combinations in different years:

1. R1m - medic included in the rotation of canola/cereal/crop or pasture legume
2. R2v – vetch include in the rotation of cereal/vetch/canola
3. R3 – an alternative crop pasture legume included in a legume/cereal/canola rotation
4. R4 - as above but with an alternative legume
5. R5 – a continuous wheat crop all years
6. R6 - trap crop included in rotation e.g. mustard or canola
7. R7 – a continuous pasture, either volunteer pasture or planted medic pasture

Crops and herbicides for each plot are listed in Table 1. In 2005, some untreated areas, including alleyways, were used for additional herbicide treatments.

After the first year of the trial when group B herbicides were found to provide the best control of broomrape, rotations were designed to develop crop and herbicide options around a group B strategy. Legumes needed to be fitted carefully into the rotation due to the soil persistence of the group B herbicides and the sensitivity of this crop to these residues. Vetch, which may be sensitive to the sulfonylurea herbicides, followed cereals. Oats or triticale with MCPA or 24D followed Logran and then vetch could be used in the following year. Glyphosate on vetch late in the season should control weed seed set for a following wheat crop. Spinnaker may be less persistent than other group B herbicides so is useful in a rotation. A legume crop can follow canola as the plant back times for the canola herbicides are sufficient. The use of canola as a catch crop in the first season was not successful but canola was kept in rotations as a good break crop.

Although the plots were used until 2008, the design of the trial changed to allow the testing of more herbicides in 2005 and 2006 and all plots were converted to pasture in 2007 to allow for testing of herbicides for pasture. This report covers the first six years of the rotation trial.

Herbicide application was by a quad bike sprayer with a 6 m shielded boom applying 120 L water ha^{-1} travelling at about 7 km h^{-1}. Herbicides were applied with adjuvants as recommended by the manufacturer. They were typically applied from late July to August although some applications to crops were before sowing or before crop emergence. The comparison of broomrape emergence between treated and untreated plots gave the assessment of herbicide efficacy. Emerged broomrape was counted in late spring by subsampling or counting all plants present in the plot (Matthews 2002, Matthews et al 2006).

Table 1. Crops and herbicides (rate per hectare) used in the rotation trials. Shaded squares had emerged broomrape in treated plots.

Rotation	2001[1]	2002[2]	2003[3]	2004[4]	2005[5]	2006[6]
R1m	**Medic** Glyphosate (300 ml)	**Clearfield and Oscar canola** OnDuty (40 g)	**Wheat** 24D600 (500ml) + Lontrel (60ml)	**Medic** Raptor (45g)	**Wheat** Eclipse (3.5g)	**Angel medic** Various herbicides#
R1m	**Galleon barley** Ally (5g)	**Medic** Spinnaker (70g)	**Clearfield canola** OnDuty (40g)	**Krichauff wheat** Logran (10g)	**Medic** Glyphosate (500ml) Glyphosate 500ml + Ally (1g)	**Angel medic** Broadstrike Broadstrike + Hero
R1m	**Clearfield canola** OnDuty (20g)	**Krichauff wheat** Ally (3g)	**Triticale** 2,4 D 600 (500 ml)	**Clearfield canola** ClearSol (56mls)	**Canola** OnDuty (40g)	**Krichauff wheat** Ally (3g) Ally (5g) + MCPA Eclipse
R2v	**Frame wheat** MCPA (1L)	**Vetch** Glyphosate (1.5 L)	**Wheat** Logran B Power (15g)	**Wheat** Eclipse (5g) + MCPA (300mls)?	**Popany vetch** Broadstrike (25g)	**Clearfield canola** OnDuty (40g) Eclipse (7g) Flame
R2v	**Frame wheat** Logran (30 g)	**Triticale** MCPA (1 L)	**Vetch** Glyphosate 540 (500ml)	**Clearfield canola** OnDuty (40g)	**Wheat** Midas (900ml)	**Vetch and oats** Staple KIH
R2v	**Vetch** Glyphosate (300ml)	**Clearfield canola** OnDuty (40g)	**Wheat** Midas (900 ml)	**Vetch** Broadstrike 25g	**Clearfield canola** Clearsol 28 ml Clearsol 42 ml Clearsol 56 ml	**Vetch and oats** Staple KIH
R3	**Clearfield wheat** Midas (600 ml)	**Peas** Spinnaker (70g)	**Clearfield canola** On Duty (40g)	**Clearfield wheat** Midas (900 ml)	**Lupin** Eclipse (7 g) Simazine (1 L)	**Volunteer pasture** Lontrel + MCPA500 (500ml) Bromoxynil (500ml)
R3	**Medic** Glyphosate (300ml)	**Medic** Glyphosate (1.5 L)	**Wheat** MCPA (1 L) + Lontrel (60 ml)	**Medic** Glyphosate (1L)	**Wheat** Ally (3g)	**Lupin** Simazine + Eclipse KIH Staple
R4	**Oscar canola** Glyphosate (300 ml)	**Clearfield wheat** Midas (900 mls)	**Parafield peas** Spinnaker (70 g)	**Krichauff wheat** Ally (3g) + MCPA (300mls)	**Peas** Spinnaker (70 g)	**Herald medic** Broadstrike Broadstrike + malathion Broadstrike + Bromoxynil
R4	**Clearfield & Oscar canola** OnDuty (20 g)	**Krichauff wheat** Logran (12g)	**Oats** MCPA (1L)	**Parafield peas** Spinnaker (70g)	**Wheat** Logran B Power (15 g)	**Peas** Sencor Spinnaker
R5	**Frame wheat** Glean (7.5 g)	**Krichauff wheat** Glean (7.5g)	**Krichauff wheat** Glean (12g)	**Krichauff wheat** Glean (10g)	**Krichauff wheat** Glean (10g)	**Wheat** Glean (10g) Ally (5g)
R6	**Mustard & radish** Glyphosate (300ml)	**Barley** Ally (5g)	**Medic** Glyphosate (1L)	**Canola** OnDuty (40g)?	**Canola** OnDuty (40 g)	**Canola** OnDuty (40g) Eclipse (7g) Flame
R7	**Volunteer pasture** Glyphosate (300 ml)	**Volunteer pasture** Glyphosate (1.5 L)	**Volunteer pasture** Glyphosate (1L)	**Medic pasture** Broadstrike 25g	**Medic pasture** Broadstrike (25 g) Broadstrike 25g + Bromoxynil	**Herald medic** Broadstrike (25g) Staple KIH

[1] 2001 results from Matthews 2002

[2] 2002 results and rates from Broomrape News Vol 3, Issue 1, February 2003

[3] 2003 results from Broomrape News Vol 5, Issue 1, February 2004

[4] 2004 results from Agronomy Matters Vol 2, Issue 1, 2005

[5] 2005 results and treatments from Broomrape News Vol 7, Issue 1, 2006

[6] 2006 results from Broomrape News Vol 8, Issue 1, 2007

[#] Herbicides planned for use were Monza, Ally, Flame, Raptor, Hussar, Broadstrike, Spinnaker, OnDuty, Intervix, KIH, Express, Bromoxynil. There is no data available on the final selection or results. Seven herbicides were successful at suppressing broomrape emergence.

Results

2001

Overall broomrape emergence was low in this year. Several Group B herbicides gave 100 % control of emergence (Table 2). These included the sulfonylurea herbicides, Logran™, Glean™ and Ally™ and the imidazolinone OnDuty™. Glyphosate was less successful for control over a range of crop types although broomrape emergence was less in these plots than untreated control plots. Higher rates of glyphosate were used in later trials.

The first year results showed that there was scope for reliable herbicide suppression of *O. ramosa* on the weedy hosts in cereal crops and possibilities for control in legume or brassica crops with adjustment of glyphosate rates or herbicide choices and time of application.

Table 2. Emergence of branched broomrape in herbicide treated plots in 2001

Crop	Herbicides and application rate (ha^{-1})	Mean broomrape emergence (m^2)
Barley	Ally (5 g)	0
Clearfield canola	OnDuty (20 g)	0
Frame wheat	Glean (20 g)	0
Frame wheat	Logran (30 g)	0
Medic 100 kg ha^{-1}	glyphosate (300 ml)	0
Vetch	glyphosate (300 ml)	0.03
Medic 20 kg ha^{-1}	glyphosate (300 ml)	0.04
Clearfield canola and Oscar	OnDuty (20 g)	0.07
Mustard and turnip	glyphosate (300 ml)	0.07
Oscar canola	glyphosate (300 ml)	0.19
Clearfield wheat	Midas (600 ml)	0.21
Volunteer pasture	glyphosate (300 ml)	0.89
Frame wheat	MCPA (1L)	1.41
Mean of all treatments		0.22
Mean of all untreated plots		1.68
Mean of untreated pasture		3.3

From Matthews 2002

2002-2004

Broomrape emergence in 2002 was low, with an average of 0.71 broomrape plants m^{-2} in untreated plots. Most herbicides were successful in preventing broomrape emergence in this season (see unshaded cells in Table 1).

In 2003, rain events into spring increased the length of the growing season and there was high broomrape emergence in untreated plots (Fig. 2). Emergence was lowest in untreated plots with wheat crops but the other cereal crops had high emergence. Broomrape plants were also abundant in untreated host crops, with the highest number occurring in the continuous volunteer pasture plots. Although several herbicides failed to completely suppress emergence (Table 2 and 4), all herbicides substantially reduced broomrape abundance compared to untreated plots.

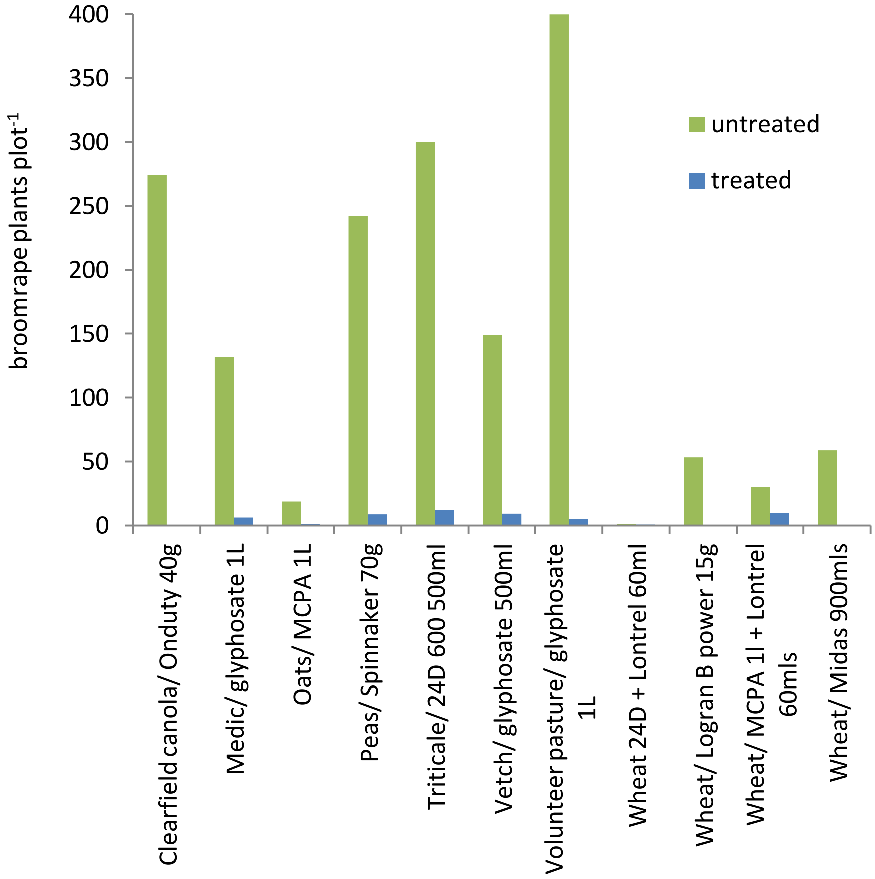

Figure 2. Broomrape emergence in treated and untreated plots in 2003. Herbicide rates are per hectare. The y axis has been truncated at 400 but there were 2,494 broomrape plants in volunteer pasture plots. Each bar is the mean of 6 plots.

Conditions were dry during the 2004 season although there was consistent broomrape emergence across untreated plots (Table 3). Broadstrike was the only herbicide that failed and this occurred in vetch and medic crops where cretan weed was present and the herbicides failed to control this weed (Table 3). There was no broomrape emergence in treated cereal or canola crops.

Wheat yields were sampled in 2004 before the late season rain (Table 4). Grain protein averaged 10.1%.

A summary of the herbicide results from 2002 to 2004 is shown in Table 5. The group B herbicides continued to be the most effective for preventing broomrape emergence in all crop types. Broadstrike was the only group B herbicide that was not effective. Of the other herbicide groups, only glyphosate was successful in suppressing broomrape emergence.

Table 3. Emergence of broomrape in treated and untreated plots in 2004.

Crop	Herbicide	Broomrape emergence plot^{-1} untreated	treated
medic	Glyphosate (1 L)	22.5	0
wheat	Eclipse (5 g) + MCPA (300 ml)	10	0
canola	OnDuty 40 g	7.5	0
vetch	Broadstrike (25 g)	65	157.5
canola	ClearSol (56 ml)	20	0
wheat	Midas (900 ml)	7.5	0
medic	Raptor (45 g)	7.5	0
wheat	Ally (3 g) + MCPA (300 ml)	22.5	0
peas	Spinnaker (100 g)	10	0
wheat	Logran (10 g)	10	0
wheat	Glean (10 g)	12.5	0
canola	OnDuty (40 g)	0	0
medic	Broadstrike (25 g)	5	17.5

Table 4. Krichauff wheat yields from treated and untreated plots in 2004.

Treatment	Yield (t ha^{-1})
untreated	1.37
Logran	1.32
Glean	1.19
Ally + MCPA	0.67

There was one rotation where emerged broomrape was not found in treated plots (R1m, Table 1). This was a cereal/medic/canola rotation with group B herbicides used in all years. Emerged broomrape was not found in the continuous wheat plots either. Rotations that included glyphosate as a herbicide choice typically had recurring broomrape emergence. Of the Group B herbicides, Broadstrike and Raptor were not successful for preventing broomrape emergence in medic and Broadstrike was also ineffective in vetch. Spinnaker in peas was only successful at rates of 100g ha^{-1}.

2005

In 2005 there were good spring rains so broomrape emerged over a longer period, from late September until the beginning of December. The good winter and extended spring meant that some herbicides with inadequate persistence allowed some broomrape to emerge in crop and herbicide choices that had successfully prevented broomrape emergence in other years (see shaded cells in Table 1). The plots that had been continuously cropped with wheat had no emergence.

Although herbicides were not able to completely prevent broomrape emergence they did substantially suppress the number of broomrape plants under conditions that produced a high abundance of broomrape in untreated plots (Fig. 3). In most cases where there were herbicide failures, broomrape emergence was less than 1 plant per square metre in treated plots.

Table 5. Herbicides, rates and mean efficacy (average across 1 or more trials in 2002 - 2004) on branched broomrape measured by comparison of treated and untreated areas.

Herbicide	Active ingredient	% control ± SD
Cereals		
Glean 12 g ha^{-1}	chlorsulfuron	100
Ally 3 g ha^{-1}	Metsulfuron methyl	100
Logran 15 g ha^{-1}	triasulfuron	100
Midas 900 ml ha^{-1}	MCPA + imazapic + imazapyr	100
Midas 450 mls ha^{-1}	MCPA + imazapic + imazapyr	100
Eclipse 5 g + MCPA500 300 mls ha^{-1}	Metosulam + MCPA	100
Ally 3 g + MCPA500 300 ml ha^{-1}	Metsulfuron methyl + MCPA	100
Logran B Power 15 g ha^{-1}	Triasulfuron + butafenacil	100
MCPA500 1 L ha^{-1}	MCPA	91 ± 1
MCPA 700 mls ha^{-1}	MCPA	67 ± 17
MCPA 1 L + Lontrel 60 mls ha^{-1}	MCPA + clopyralid	68 ± 15
24D600 500 mls + Lontrel 60 mls ha^{-1}	24D + clopyralid	60 ± 1
24D600 500 mls ha^{-1}	24D	92 ± 12
Canola		
OnDuty 40 g ha^{-1}	Imazapic + imazapyr	100
OnDuty 30 g ha^{-1}	Imazapic + imazapyr	100
ClearSol 56 mls ha^{-1}	imazapyr	100
Peas		
Spinnaker 100 g ha^{-1}	imazethapyr	100
Spinnaker 70 g ha^{-1}	imazethapyr	74 ±
Vetch		
Glyphosate540 500 mls ha^{-1}	glyphosate	97 ± 4
Broadstrike 25 g ha^{-1}	flumetsulam	142
Medic pasture planted		
Spinnaker 100 g ha^{-1}	imazethapyr	100
Glyphosate540 500 mls + Ally 2g ha^{-1}	Glyphosate + metsulfuron methyl	100
Glyphosate540 500 mls ha^{-1}	glyphosate	89 ± 20
Broadstrike 25 g ha^{-1}	flumetsulam	250
Volunteer pasture		
Glyphosate540 1L ha^{-1}	glyphosate	99 ± 1
Typical emergence (means ±1 SD) in untreated plots was 15.4 ± 22.7 m^2 in cereals, 25.1 ± 35 in canola, 20.9 ± 24 in legume crops and 10 ± 14.6 in medic pastures		

From Matthews et al 2006

2006

Break of season rains were early in 2006 and there were adequate winter rains but there was a dry end to the season. Broomrape populations developed well on the early developing host weeds with an average of 5 to 6 emerged plants on cretan weed plants at the trial site. Broomrape emergence was completely suppressed in cereal, lupin and canola crops. A newly trialled group B herbicide, Staple (a.i. pyrithiobac-Na), was effective applied pre or post crop emergence in vetch although this herbicide is only registered for use in cotton. Emergence was not prevented in Herald medic or volunteer pasture but several treated Angel medic plots had no emergence (compare shaded and unshaded cells in Table 1). Broadstrike was not successful in preventing emergence although the addition of malathion (an inhibitor of herbicide metabolism) improved efficacy by 50%.

There are no results for the measurement of seed bank reduction under the various rotations.

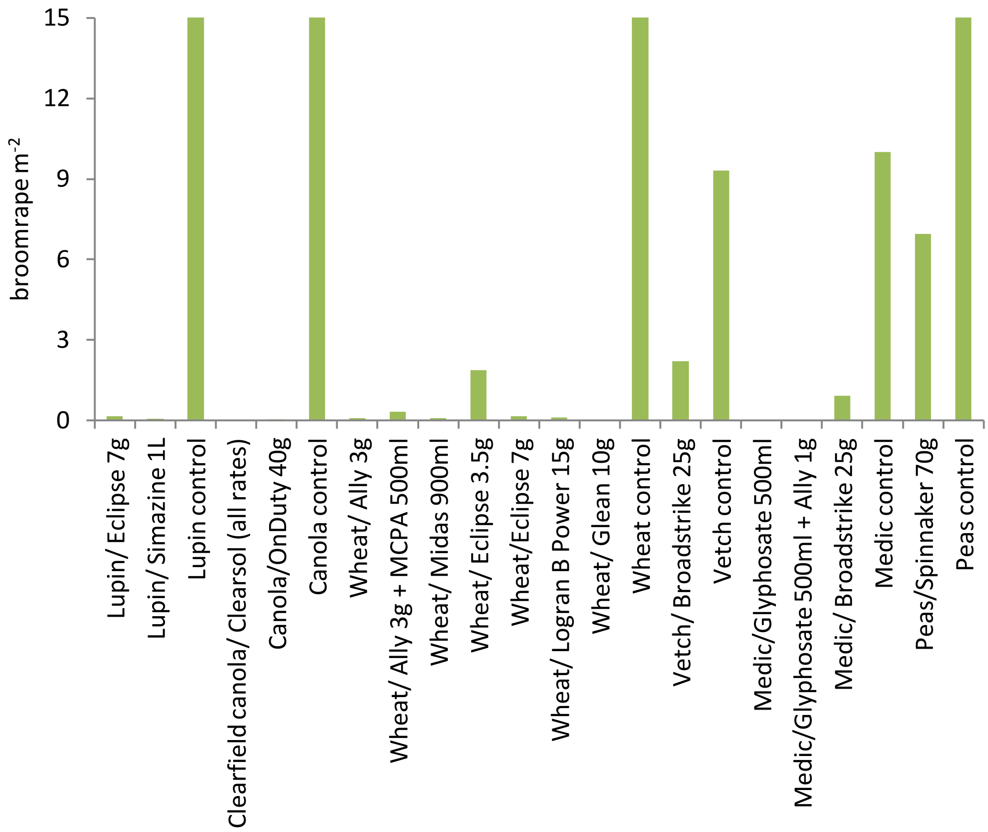

Figure 3. Broomrape emergence in rotation plots in 2005. The y axis has been truncated at 15 but some control plots had up to 36 plants m^{-2}. Each bar is the mean of 6 plots.

Discussion

The herbicides that inhibit branched chain amino synthesis via acetolactose synthase, i.e. the sulfonylurea, imazidolinone and sulphonamide herbicides (Group B) consistently prevented broomrape emergence in the variety of crops used in this trial. For cereals, the most successful herbicides were Glean, Logran, Logran B Power, Ally and Ally mixtures, Eclipse and Midas. Herbicides from the same group and selective on other crop species were OnDuty, ClearSol, Spinnaker and Raptor. Use of these herbicides may lead to effective and low cost control if their use can be integrated into a sustainable farming system. Branched broomrape is largely confined to an area in which the favoured land use is cereals with a short pasture ley; this presents opportunities for control in the cereal phase. The challenge is to identify effective herbicide rates that can be used profitably in the crop, without causing carryover problems in the pasture or legume phases in the farming system. As eradication is the goal of the program, only 100 % control of emergence is considered acceptable.

Glyphosate, which inhibits EPSP synthase, also provided good control but in the absence of glyphosate-tolerant crop species, is limited to some particular situations in the cropping cycle.

In situations where cereal crops are grown, eliminating all broomrape hosts is a potential method of control and the phenoxy-acetic acid herbicides could be used for that purpose. The duration of the effect of these herbicides is brief and there remains potential for regrowth or further germination of weeds. MCPA and 2,4D are widely used in the area but there is a risk of failure due to poor kills, regrowth or fresh germination of hosts as in some seasons there is no residual effect. These herbicides are more effective if mixed with a low rate of a group B herbicide, with Lontrel being useful if capeweed is present.

Efficacy against broomrape varies according to seasonal conditions and host plant tolerance to herbicide. Application rate also determines the efficacy of the product and the application rates used represent the lower end of the usual rates as the soil pH and rainfall determine carryover effects which can influence crop choice or pasture vigour in subsequent years. Many herbicides gave 100% control of broomrape emergence in all or some of the years of testing. Many of the non-persistent herbicides were applied late in the crop or pasture growth cycle to target broomrape emergence. There may be cases where optimum crop performance could be better achieved by earlier application of these products.

Acknowledgements

This research was funded by the Grains Research and Development Corporation and the CRC for Australian Weed Management.

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3. Sown pasture herbicide trials

John Matthews

CRC for Australian Weed Management, University of Adelaide

Report compiled by Jane Prider

Introduction

Pastures comprise the highest land use of infested paddocks within the quarantine area. Control of broomrape is often difficult in this situation as many of the broad-leaf pasture species are hosts and selective herbicides suitable for these species do not always suppress broomrape emergence. Late season applications can be effective but there is a need to maintain feed following spraying and ground cover to prevent erosion. The treatments that prevent broomrape emergence can be expensive for use in low rainfall environments especially in a pasture phase. In 2003, sown perennial pastures were established in order to test some management options for broomrape in a grazing situation. Although perennial pastures may not fit easily into a cropping rotation, the productivity of these species at times of the season when annual feed is short is worthy of consideration.

Methods

Replicate plots were prepared for sowings of Lucerne, Herald medic and veldt grass at the Mannum Trial Site. Lucerne cv. Hunterfield was sown into deep-ripped plots on May 15th 2003. Other crops were planted on May 26th 2003. Plots were fertilised with 50 kg ha^{-1} of triple super + zinc. In 2005, medic and some volunteer pasture plots were burnt and the medic plots were sown with medic and oats, both at rates of 20 kg ha^{-1}.

Plots remained ungrazed after establishment.

Herbicide treatments were applied to plots between 2003 and 2006 as described in Table 1. Herbicide application was by a quad bike sprayer with a 6 m shielded boom applying 120 L water ha^{-1} travelling at about 7 km h^{-1}. Herbicides were applied with adjuvants as recommended by the manufacturer. The number of replicate plots for each treatment varied between 3 and 6 each year.

Broomrape plants were counted in treated and untreated plots after emergence in spring. Plants were counted in the entire plot or when abundant, within a one metre quadrat within each plot.

Results

2003

There were good conditions for broomrape emergence in this season. There was broomrape emergence in all pasture plots in 2003 although treated plots had fewer plants than untreated plots (Figs 1 & 2). Spinnaker failed to completely suppress emergence in lucerne even at the highest rate of 100g. Ally plus Lontrel provided the best control of broomrape in veldt grass whilst Raptor provided better control than Broadstrike in Herald medic (Fig. 2).

Table 1. Perennial sown pasture herbicide treatments 2003-2006.

Pasture	Lucerne		Herald medic		Veldt grass	
	herbicide	rate	herbicide	rate	herbicide	rate
2003	Raptor	11 g	Broadstrike	25 g	Ally	2.5 g
		22 g	Raptor	22 g	Ally + Lontrel	2.5 g + 60 ml
		33 g				
	Spinnaker	12 g				
		25 g				
		50 g				
		100 g				
	Broadstrike	15 g				
		25 g				
	Broadstrike + bromoxynil	15 g + 1.4 L				
2004	Spinnaker	70 g	glyphosate	500 ml	Ally	3 g
		100 g		1 L	Ally + MCPA	3 g + 300 ml
	Broadstrike*	25 g	Glyphosate + Ally	500 ml + 1 g		
	Broadstrike	50 g	Broadstrike	25 g		
	Raptor	45 g	Raptor	45 g		
		60 g				
2005	Spinnaker	140 g	Glyphosate	500 ml	Ally	3 g
	Raptor	45 g	Glyphosate + Ally	500 ml + 1 g	Ally + MCPA	3 g + 500 ml
	Broadstrike	50 g	Hero	7.5 g		
	Paraquat + Diuron	?		10 g		
			Broadstrike	25 g		
			Express	1 g		
				7.5 g		
			Envoke	0.75 g		
				1 g		
2006	Spinnaker	?			Spinnaker	?
	Ally	?			Ally	?

*Double application on July 27th and September 14th

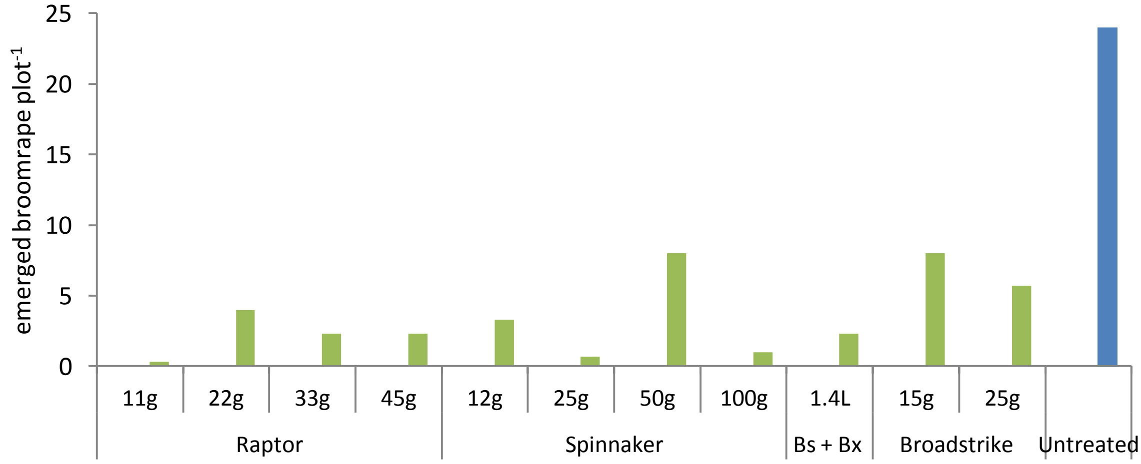

Figure 1. Broomrape emergence in herbicide-treated or untreated lucerne pasture in 2003. Each bar is the mean of six replicate plots.

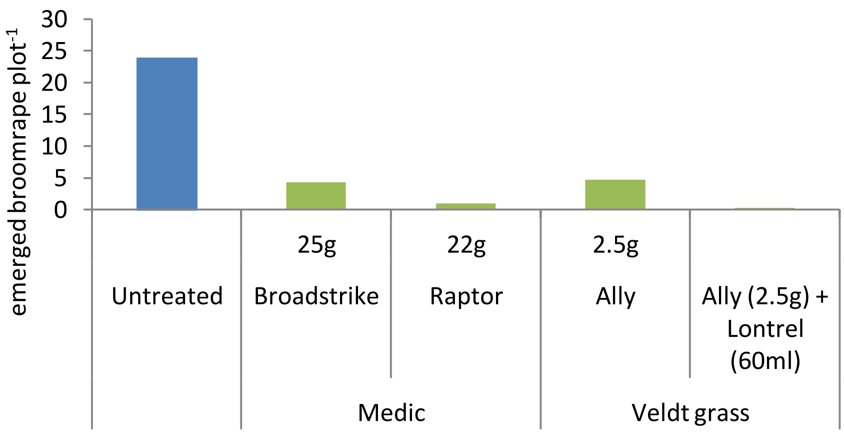

Figure 2. Broomrape emergence in herbicide-treated or untreated Herald medic and veldt grass pasture in 2003. Each bar is the mean of six replicate plots.

2004

In 2004, plots were weedy and had broomrape hosts present although the dry finish to the season reduced broomrape emergence. Emergence was variable in the untreated plots, with some control plots having no broomrape. Broomrape did not emerge in any of the treated or untreated veldt grass plots. Spinnaker, which is registered for lucerne and peas, suppressed emergence in lucerne plots but control plots did not have any broomrape (Fig. 3). Broadstrike and Raptor failed to suppress broomrape emergence in lucerne. Broomrape did not emerge in 2004 in any of the Herald medic plots treated with glyphosate, glyphosate with Ally or Raptor but Broadstrike failed to prevent emergence (Fig. 3).

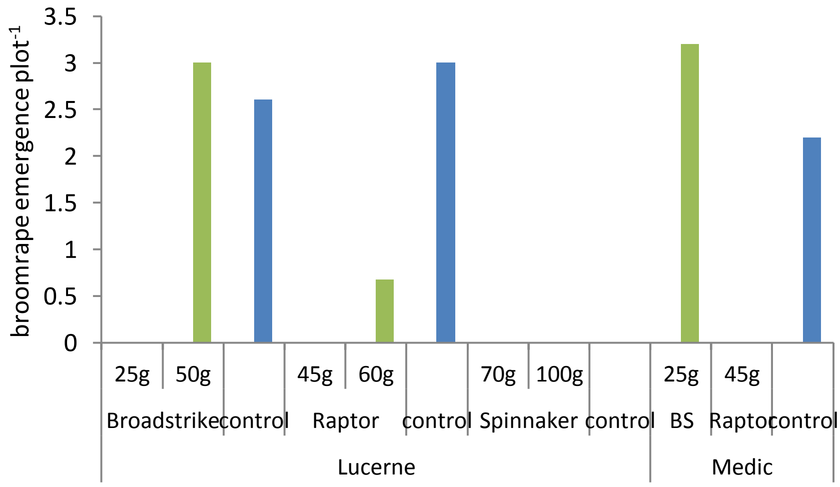

Figure 3. Broomrape emergence in herbicide-treated or untreated lucerne and medic pastures in 2004. Veldt grass pastures not shown (no emergence).

2005

There was a late start to the annual pasture growth this year but by August Lucerne and veldt grass pastures were growing well (Broomrape News Vol 6 (3) August 2005) and there were good spring rains. Emergence occurred over 11 weeks from late September until December. Of the new herbicides trialed in Herald medic in 2005, the sulfonylurea herbicide Hero, provided more effective control of broomrape than the other group B herbicides, Express, Envoke or Broadstrike (Fig. 4). Glyphosate and Glyphosate plus Ally provided the best suppression of broomrape in Herald medic plots this season. There was low broomrape emergence in all lucerne and veldt grass so the effectiveness of herbicides for broomrape control was not conclusive (Fig. 5). In volunteer pastures, Broadstrike plus Hero provided better suppression of broomrape than Broadstrike alone (Fig. 5).

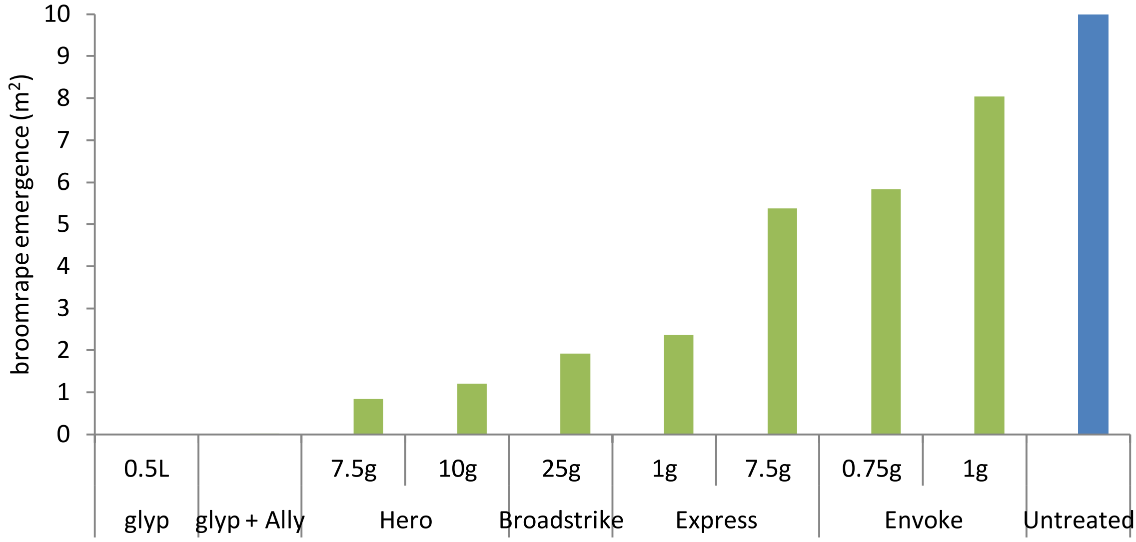

Figure 4. Broomrape emergence in herbicide-treated or untreated Herald medic pastures in 2005. Each bar is the mean of three replicate plots.

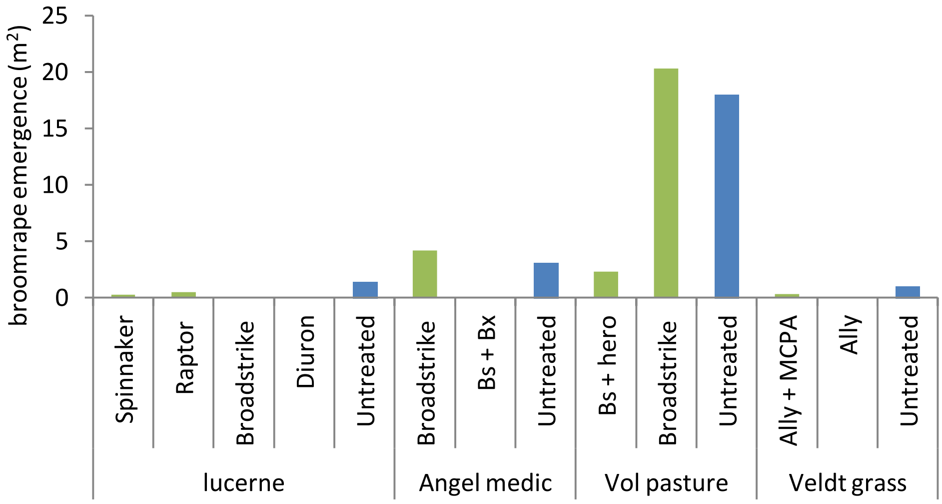

Figure 5. Broomrape emergence in herbicide-treated or untreated sown and volunteer pasture in 2005. Each bar is the mean of three replicate plots.

2006

This season there was an early start with adequate winter rains but poor rains through spring. The first emergence in trial plots occurred on September 11th and continued for six weeks. There was no emergence in veldt grass or Lucerne plots treated with Spinnaker or Ally this season.

Discussion

No herbicide gave complete suppression of broomrape across all years of the trial but many herbicides successfully reduced broomrape emergence in comparison with untreated plots. Variability in broomrape emergence masked any differences between those herbicides applied at different rates. Broadstrike applied twice to Lucerne in 2004 suppressed emergence whilst a single late application of 50 g Broadstrike did not. Further work is required to confirm whether a double application of this herbicide is consistent as of all the herbicides Broadstrike is possibly the weakest performer. Broadstrike in mixture with either Hero or bromoxynil was effective in 2005, possibly through controlling cretan weed.

Spinnaker is more effective than Broadstrike or Raptor in lucerne but is only registered for this crop or peas. However this herbicide can persist in high pH, low rainfall environments for over two years, limiting plant back options so may only be suitable in a long-term lucerne phase.

4. Other herbicide trials by John Matthews

John Matthews

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Report compiled by Jane Prider

These are results from several herbicide trials run by John Matthews from 2001 to 2008. The Mannum Trial Site was used for most of the trials and they provide additional testing of herbicides, rates and timings that supplement the results of larger trials.

With the successful control of broomrape with group B herbicides several of these trials examined whether lower rates of group Bs would suppress emergence. Low rates would reduce the cost of herbicide application and minimize plant back restrictions.

New group B herbicides were tested as they became available. Occasionally these were tested in situations for which they have not been registered.

Some herbicides that did not provide 100% control were tested with double applications and adjustments to the timing of application.

Table 1. Results of various herbicide trials from 2001- 2008 for the suppression of broomrape emergence.

Crop or situation used in trial	year	Herbicides and rates ha^{-1}	result	comments
Clearfield canola	2001	Glean (5 g) Logran (7 g) Ally (1.25 g)	No emergence in treated plots, average of 10.3 emerged in untreated plots	
Clearfield canola	2004	Clearsol (42 ml) Clearsol (84 ml)	No emergence	Clearsol at recommended rate of 56 ml was used in rotation trial – also 100% control
Medic pasture	2001	Raptor (45 g) early Raptor (45 g) late	Emergence higher than control plots	
Volunteer pasture	2003	Eclipse (5 g)	75 ± 4% control	Eclipse can also be used in wheat and some lupin varieties
Volunteer pasture	2003	Spinnaker (25 g)	62% control	
Volunteer pasture		Sulfometuron methyl (20 g)	100% control	
uncropped areas	2002 2004	rimsulfuron (30 g)	100 % control	Registered for use in tomato and potatoes
uncropped areas	2002-	Oust (50 g)	100% control	

Crop or situation used in trial	year	Herbicides and rates ha^{-1}	result	comments
	2004			
uncropped areas	2001	Glean (5 g)		
vetch	2006 2007	Staple (20g) pre crop emergence Staple (60 g) post crop emergence	100% control	Some damage to vetch, cv. Cappello least affected
Cereal	2002-2004	Atlantis (330 ml) Monza (25 g) Hussar (150 g)	Atlantis 64% control, Monza and Hussar no emergence	
Cereal	2002-2004	Logran (7.5 g) late application	83 ± 19% control	
Krichauff wheat	2004	Eclipse (3.5 g) Eclipse (7 g) Glean (5 g)	No emergence	These are lower rates of these herbicides used in the main rotation trial
Wheat & Pasture	2008	Crusader (500 ml) Crusader (250 ml)	No emergence but also no emergence in wheat controls. 4.5 emerged in pasture controls (n = 4)	a.i. pyroxsolan and cloquintocet-mexyl

5. Management of broomrape in horticultural crops

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2006

Background

Research efforts in broadacre situations have led to the identification of herbicides that will eradicate broomrape in cereal crops, some host crops and pastures. However, gaps still remain in finding appropriate herbicides for controlling broomrape in onions, vineyards and orchards.

The current BBR database identified 22 properties with either Level 3 (no BBR within arable area of paddock but found in non-arable areas) or Level 4 (BBR found within arable area of the paddock) horticultural crops. The crops identified on the data base as being grown in those areas or on those properties included onions, potatoes, vines, oranges, apricots, almonds, olives and cherries.

The herbicides Titus® (250 g/L rimsulfuron), Express® (750 g/L tribenuron methyl) and Envoke® 750 g/L trifloxysulfuron sodium) may have potential uses in onions. Quality Assurance issues restrict some horticultural growers using products not registered for use in specific crops, however it is still considered important to try novel herbicides as an alternative to pine-oil.

Treatments

Application of pine-oil was trialled in almonds, olives, cherries, apricots and vines to assess the effectiveness of the product in horticultural situations on weed control and the tolerance of crops to post emergence treatments.

The treatments were applied inter-row in the above crops as close as possible to the tree row to ensure that product was applied up to and in most situations onto the base of the tree or vine.

See Table 1 for treatment details.

Table 1: Pine oil (Interceptor®) treatments in orchards and vineyards.

Application Equipment	Water Application rate (Litres / hectare)	Pine oil concentration (%)	Rate of pine oil (Litres / hectare)
"Broominator"	5,000	20	1,000
	10,000	10	1,000
	20,000	5	1,000
Conventional	750	15	112.5
Boomsprayer	1,000	15	150
	1,000	10	100
	1,500	10	150

The trials were assessed visually. Photographs were taken at the time of application, and after application.

Pot experiments were established to determine the effect of pine oil and the herbicides Titus®, Express® and Envoke® on the establishment of onions after the application of these products and also on the effect of pine oil applied post emergent to onions at two application times.

See Table 2 and Table 3 for details of these treatments.

This trial was conducted under glasshouse conditions at the Plant Research Centre, Waite.

The effect of the pre-emergent treatments on plant emergence was assessed by counting emerged plants. The effects of the post-emergent treatments was assessed visually.

Table 2. Pre-sowing herbicide and Pine oil (Interceptor®) treatments in onions.

Product	Days before seeding	Water Application rate (if applicable) (Litres / hectare)	Concentration (If applicable) (%)	Rate of Product/hectare
Titus®	0	n/a	n/a	60 g
	7			60 g
	21			60 g
Express®	0	n/a	n/a	30 g
	7			30 g
	21			30 g
Envoke®	0	n/a	n/a	30 g
	7			30 g
	21			30 g
Pine oil	0	1,000	15	150 L
	7	1,000	15	150 L
	21	1,000	15	150 L
Pine oil	0	20,000	5	1,000
	7	20,000	5	1,000
	21	20,000	5	1,000

Table 3. Post emergent Pine oil (Interceptor®) treatments in onions.

Onion Growth Stage	Water Application rate (Litres / hectare)	Pine oil concentration (%)	Rate of pine oil (Litres / hectare)
3 leaf	400	15	60
	600	15	90
	800	10	80
	800	15	120
	1,000	10	100
5 leaf	400	15	60
	600	15	90
	800	10	80
	800	15	120
	1,000	10	100

Results

Orchards and Vineyards

The treatments caused no observable effects on the growth of any of the tree crops or vines tested.

Where spray mixture contacted green leaf at the time of application the leaves were dessicated. However, there was no observed effect on future growth from these stems or branches.

Weed control was variable. The trials were assessed between 14 and 21 days after application.

The amount of dessication tended to be greater where the treatments were applied with the “broominator” (ie very high water and product rate / hectare). In all except one trial trial these rates (1,000 L/ha product) gave useful control of the weeds present. (ie greater than 90% control).

When the treatments were applied with a conventional boomsprayer and water rates and the rate of product was reduced (100 to 150 L/ha product) the results were not acceptable. The best control obtained was at one site where 150 L/ha pine oil gave 75% control of wild oats. At another site 150 L/ha of pine oil gave 58% control of silver grass.

Not all weeds were present at all sites. However, there was some evidence that some plants were more sensitive than others. Although the results were poor the most susceptible plants, in order of control, obtained appeared to be wild oats, silver grass, barley grass, prairie grass, hawkbit and medic. Cretan weed was present at one and useful control was obtained at 1,000 L/ha of product applied with the “broominator” but not at lower rates applied with a conventional boomsprayer.

Onion pot trials

In the pre-emergent trial the three herbicides tested, Titus®, Express® and Envoke®, all prevented emergence of onions at all times of application.

Therefore, based on the results of this trial the plant back period for these products is at least 21 days and is most likely measured in months given that no plants emerged in any of the treatments.

The pine oil treatments did not reduce emergence significantly although there was a trend suggesting the treatments applied at the time of seeding may have caused a slight reduction in emergence.

In the post emergent trial treatments applied at the 5 leaf stage of the crop all caused some damage. Although the plants appeared to recover the damage was likely to be commercially unacceptable given that the growth was affected. The onions were not grown through to maturity . Therefore the effect on bulb production was not determined.

There was a trend for the higher water and product rates to cause greater damage.

Conclusions

The use of pine oil in orchards and vineyards for post emergent weed control alone is not effective. The benefit of this treatment on broomrape seed management was not determined in these trials.

The use of Titus®, Express® and Envoke® applied up to 21 days pre sowing onions is not recommended.

The use of pine oil applied post emergence to onions caused some damage to the onions and is therefore not likely to be commercially acceptable. The weed control that these rates would achieve is also likely to be unacceptable.

6. Glyphosate rates and timing

John Matthews

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Report compiled by Jane Prider

Introduction

Glyphosate is a herbicide commonly used for the control of several broomrape species across a wide range of hosts. The herbicide is used in the quarantine area for spray topping so there was a need to investigate rates and timing that would both control broomrape and fit in with spray top timing.

Methods

2001 and 2002

Trials of glyphosate at two different rates (250 ml and 500 ml ha^{-1}) were applied at four different times to ?medic pasture plots. Timings were:

1. 4 weeks prior to expected emergence
2. 2 weeks prior to emergence
3. At emergence
4. 2 weeks after emergence

2002

Spray topping may commence quite late in the season when broomrape has commenced emerging. This trial examined whether late-sprayed hosts, where broomrape had started emerging, would survive long enough to enable broomrape to complete the production of viable seed.

Glyphosate was added at three different rates (0.5, 1 and 1.5 l ha^{-1}) to vetch or volunteer pasture plots at the Mannum Trial Site. There were four replicate plots. Plots were sprayed either at emergence or two weeks after emergence. Weekly collections of broomrape were made the week following spraying and for up to six weeks. These have been grouped into those collected up to three weeks after spraying and from 3-6 weeks following spraying. Up to five replicate plants were collected from each plot. The casules were removed from each plant and the seeds from each capsule were pooled and an estimate of the number of viable seeds was made. Seeds were examined under a microscope so that the proportion of fully-formed and unformed seeds could be estimated. A subsample of seeds was tested for viability through a germination test with GR24 stimulant.

2003

The efficacy of glyphosate for killing broomrape seeds within maturing capsules was not known. Individual field-grown broomrape flowering spikes were drenched with varying concentrations of glyphosate to check whether glyphosate could be used for a post-emergent treatment and prevent the production of viable seeds. Plants were treated on 7/11/2003. Treatments were a 2% or 10% solution of 540 g L^{-1} glyphosate and untreated controls. There were four replicate treatments but only one control.

The seeds were collected from 2 – 6 plants in each treatment replicate. Immature seeds were not included but where no seed was found those samples have been included as zero values. Viability was estimated from germination tests with GR24 stimulant but there was very poor germination of controls.

Results

Applications of glyphosate at 500 mL ha^{-1} failed to prevent further emergence when sprayed onto plots two weeks after broomrape started emerging. All other treatments (at emergence and 2 or 4 weeks prior) were successful in 2001 but not in 2002. Plants sprayed with low rates very early (4 weeks before emergence) or plants sprayed at emergence failed to control broomrape. The untreated controls had 20 emerged broomrape per plot and vetch had 48 plants per plot. Broomrape numbers in treated plots is not known.

However, the assessment of seed viability found that later sprayed plants (two weeks following emergence) produced less fully-formed seed than plants sprayed at emergence (Fig. 1). The earlier spraying gave sufficient time for the sprayed plants to compete the full production of some seed although this was less than in untreated plants. The higher rates of glyphosate were more effective than the lower rates in the pasture plots but not in the vetch plots.

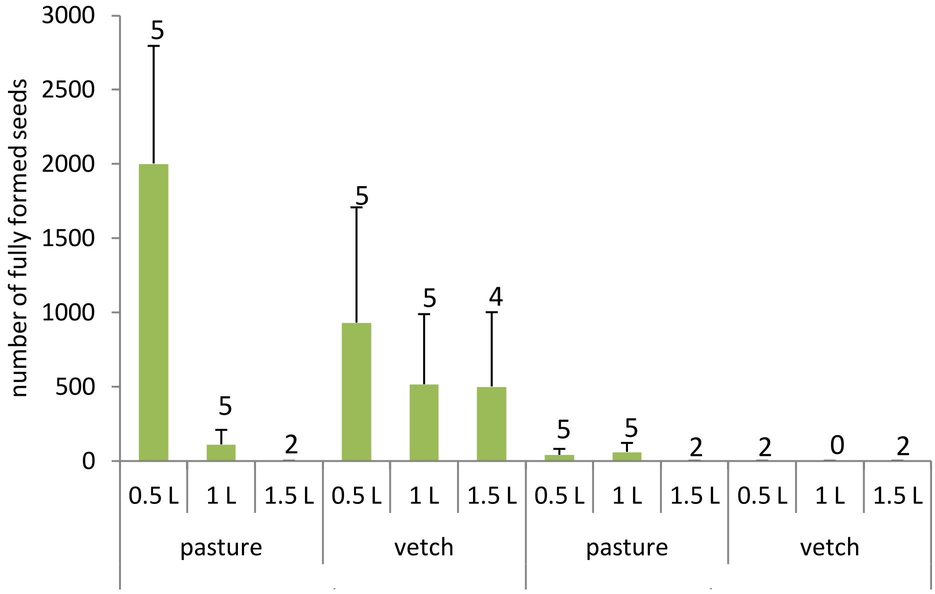

Figure 1. Estimated number of fully-formed seeds (i.e. does not include aborted ovules or small immature seeds) produced per broomrape plant in plots treated with glyphosate at three rates and two timings at broomrape emergence (early) or two weeks later (late). The numbers above each bar are the number of sampled plants with a maximum of 5 plants sampled per plot. Bars show mean and standard error for *n* = 5 (except early vetch 1.5 L, *n* = 4).

Plants drenched with glyphosate produced fewer germinable seeds than untreated plants (Fig. 2). Ungerminated seeds may have been viable but germination was also low in untreated plants. The higher concentration of glyphosate had a greater effect on germination than the lower concentration.

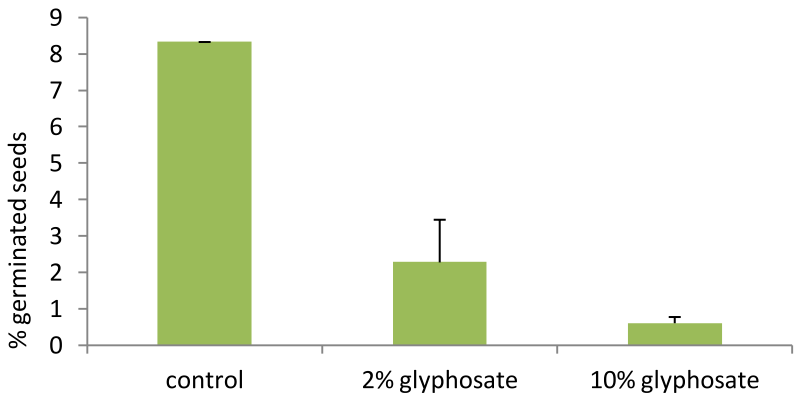

Figure 2. Germination of broomrape seeds following drenching in solutions of glyphosate (540 g L^{-1}).

Discussion

The efficacy of glyphosate varies between years but applications just prior to emergence were successful in both years. There is probably a time delay between the absorption of herbicide by the host plant and its translocation and absorption by broomrape. Spraying just before emergence would therefore not prevent broomrape plants from further growth and emergence would still occur. These plants can also complete the development of seed in this time period. Direct uptake of glyphosate by emerged plants may have resulted in a more rapid death and hence the production of fewer viable seeds by plants sprayed after emergence. Direct contact of the seed with herbicide could also reduce seed viability as it did reduce the number of germinated seeds.

The use of glyphosate at about spray-topping time may be useful in some phases of the crop rotation for seed set control in pasture paddocks destined for subsequent cropping, depending on the timing of broomrape emergence.

7. Late season glyphosate application for branched broomrape control

Jane Prider and Andrew Craig

Branched Broomrape Eradication Program

March 2012

Summary

Late season applications of glyphosate are used in the Quarantine Area to spray-top pasture in order to kill weed seeds. It is also used to control emerged broomrape plants but it is not known whether sprayed broomrape plants produce viable seed. In this experiment, glyphosate (Credit Bonus®) was applied at two rates, 300 and 500 ml ha^{-1}, at three timings; 1300 GDD, 1500 GDD and 1700 GDD, to host plants and broomrape in pots at the Mannum field site. In 2010 we used cape weed hosts and in 2011 we used cretan weed as a host. In 2010 there was no broomrape emergence though most of the sprayed capeweed was killed with no difference between spray treatments. In 2011, broomrape emergence was prevented by spraying plants at 1300 GDD. All other treatments had emerged broomrape plants that produced mature viable seed if plants were sprayed after they had commenced flowering.

Recommendations

- Glyphosate will not prevent the production of viable broomrape seed if applied post-emergence after broomrape begins flowering.
- Late pre-emergent glyphosate application is more effective for broomrape control than post-emergent application. Ideally, glyphosate should be applied at or before 1300 GDD and before broomrape plants begin emerging. If glyphosate is only applied when broomrape is confirmed as present (*i.e.* post-emergence), this should take place at the first signs of bud emergence or flower opening and before the first flowers finish to prevent the production of viable mature seed.
- A 300 ml ha^{-1} application rate of Credit Bonus is as effective as a 500 ml ha^{-1} rate.

Introduction

Glyphosate is used for the control of several broomrape species in selected crops overseas (see review by Parker and Riches 1993). Like the Group B herbicides, glyphosate is translocated from the host to the parasite where it accumulates and can result in parasite death in the absence of host effects (Arjona-Berral *et al.* 1990; Nandula *et al.* 1999). When applied after broomrape has started to emerge, the herbicide can reduce the subsequent number of spikes that emerge, although results are not consistent between broomrape species, hosts or seasons (Castejon-Munoz *et al.* 1990; Lins *et al.* 2005; Mesa-Garcia and Garcia-Torres 1985; Mesa-Garcia and Vazquez-Cobo 1985; Zahran *et al.* 1988). In field trials in the QA by Matthews (2002), glyphosate applied at the rate of 300 ml ha^{-1} (equivalent of 162 g a.i. h^{-1}) at about 750 GDD did not give complete control of broomrape emergence in several crops. A late application of glyphosate, just prior to emergence (about 1000 GDD) at a rate of 500 ml ha^{-1} (equivalent of 260 g a.i. h^{-1}), prevented broomrape emergence.

To prevent additions to the broomrape seed bank, late applications of glyphosate must affect the development of viable seeds, either when sprayed on the developing reproductive structures of emerged plants or when translocated into pre-emergent plants that may later emerge. Lins *et al.* (2005) found no effect of glyphosate on the viability of *O. minor* seeds. Matthews (2003, unpubl. results) drenched broomrape capsules in glyphosate solution. He found that a 10 % solution (equivalent 54 g a.i h^{-1}) resulted in 0.4 % germination of *O. ramosa* seed compared to up to 2 % germination in a 2 % solution and 8% germination of controls; however seed viability was not assessed. Most of the seeds in the samples were immature, including controls, and this may have affected their germination so the results are inconclusive.

Aims

Late season applications of glyphosate are used in the QA to spray-top pasture in order to kill weed seeds. Whether this practice is also effective for broomrape control remains unclear. In this experiment we will assess the following questions:

- Do late applications of glyphosate prevent emergence? Are late pre-emergent applications more effective than post-emergent applications?
- Does glyphosate kill seeds of emerged broomrape plants or plants that emerge after herbicide application? What application rate is most effective?

The outcomes from this project will enable the eradication program to:

- Evaluate the use of glyphosate for late pre-emergence or post-emergence branched broomrape control;
- If applicable, recommend to landholders the optimum time and rate for glyphosate application to control broomrape in pastures, when applied as part of regular spray-topping routines.

Methods

Pasture-topping is recommended for the control of capeweed (*Arctotheca calendula*), a widespread broomrape host. Herbicide is applied when the capeweed plants are flowering to reduce seed set. In 2010 we used capeweed as the test host. We prepared 200 mm diameter pots of Mannum field soil inoculated with broomrape seed. Pots were filled to two thirds with soil and 1 ml of broomrape seed and 5 ml of Nitrophoska® slow-release fertiliser was well mixed by hand into the top third of the soil before adding to the pots. After filling, the pots were buried to their rims in the ground at the Mannum trial site set up in five blocks each containing the replicates for all treatments. Capeweed seeds were sown on 7/6/10 from seed collected at the field site in February. Pots were watered where necessary up until 2000 GDD.

As there was no broomrape emergence on potted capeweed in 2010, the experiment was repeated in 2011, using cretan weed hosts. Pots were prepared as above with cretan weed sown on 6/6/11 and resown on 27/7/11 as earlier sowing failed.

Glyphosate, (as the herbicide Credit 540 g a.i. L^{-1} with Bonus adjuvant in 1:1 ratio) was applied at two rates (300 ml ha^{-1} and 500 ml ha^{-1}) at three timings, 1300 GDD, 1500 GDD and 1700 GDD, with a further set of replicates as unsprayed controls.

No broomrape emerged in 2010 so we estimated the proportion of capeweed live biomass in December. In 2011, we recorded the developmental stage of broomrape at the time of spraying. On 30/11/2011 we cut all emerged broomrape plants at ground level and later removed the seeds from capsules to assess viability. We used a 180 µm sieve to grade seeds, with seeds retained by the sieve designated as mature and seeds passing through as immature.

Samples of immature and mature seeds (approximately 200-500 seeds) were surface sterilised with HCl and placed in 200 µl of 1% tetrazolium solution. Seeds were incubated in the dark at 30 °C for two weeks and then the number of stained unviable seeds and stained viable seeds was counted.

The soil was washed from the roots of cretan weed plants that survived spraying but had no emerged broomrape to check for broomrape attachments.

The capeweed biomass data were analysed with a generalised linear model (GLM) with a poisson error structure. Data was over-dispersed so a quasipoisson method was used (Crawley 2007). We used *a priori* orthogonal contrasts to test for differences between treatments. These contrasts compared the 300 ml and 500 ml treatments, and each of the timings within rate levels. R software (Ver. 2.11.1) was used for the analysis. An analysis of variance (ANOVA) was used to test for the difference between cretan weed spray treatments in the number of broomrape stems and proportion of viable mature and immature broomrape seed. A Tukey test was used for pairwise comparison of treatments following the ANOVA. Genstat (Ver 10.2.0.175) was used for this analysis.

Results

2010 Capeweed

There was no broomrape emergence on capeweed hosts in any of the treatments. Glyphosate applications of 300 ml and 500ml ha^{-1} had severe effects on capeweed. Plants were killed or mostly killed by the herbicide (

Figure 1). There was no difference in the amount of surviving biomass between sprayed treatments (

Figure 1). The lower rate (300 ml ha^{-1}) was as effective as the higher rate (500 ml ha^{-1}) at all spray timings.

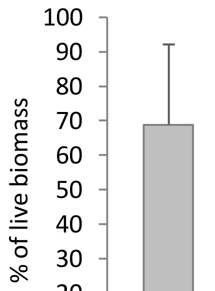

Figure 1. Amount of live biomass on capeweed sprayed with glyphosate at two rates and three timings. There were no significant differences between sprayed treatments (GLM).

2011 Cretan weed

Following the early spray at 1300 GDD, 4/5 cretan weed sprayed at 300 ml ha^{-1} survived whilst 3/5 survived the 500 ml ha^{-1} rate. None of these plants had emerged broomrape. These plants had dead non-emerged broomrape, with the exception of one plant which was not infected (500 ml treatment) and one

Figure 2. Replicates sprayed with glyphosate that did not develop broomrape seeds. Emerged broomrape is indicated by the arrows in the two lower pictures.

There was 100% cretan weed mortality for the 1500 GDD or 1700 GDD spray timings at both rates. All hosts had emerged broomrape when sprayed and the majority of these produced at least mature seed. The 6 broomrape plants that produced no seed occurred in the 300 ml ha^{-1} treatments the 500 ml ha^{-1} at 1500 GDD treatment (2 in each treatment). These plants had emerged buds or open flowers when they were sprayed (

Figure 2). Plants sprayed at 1500 GDD produced fewer broomrape stems than plants sprayed at 1700 GDD or unsprayed plants (Figure 4). Plants that were in flower or with some flowers that had finished flowering when sprayed, produced viable mature or immature seed (Figure 3). The sprayed treatments did not produce a lesser proportion of viable seed than unsprayed controls (

Figure 5).

Figure 3. Examples of plants sprayed with glyphosate that developed to produce viable, mature broomrape seed after spraying.

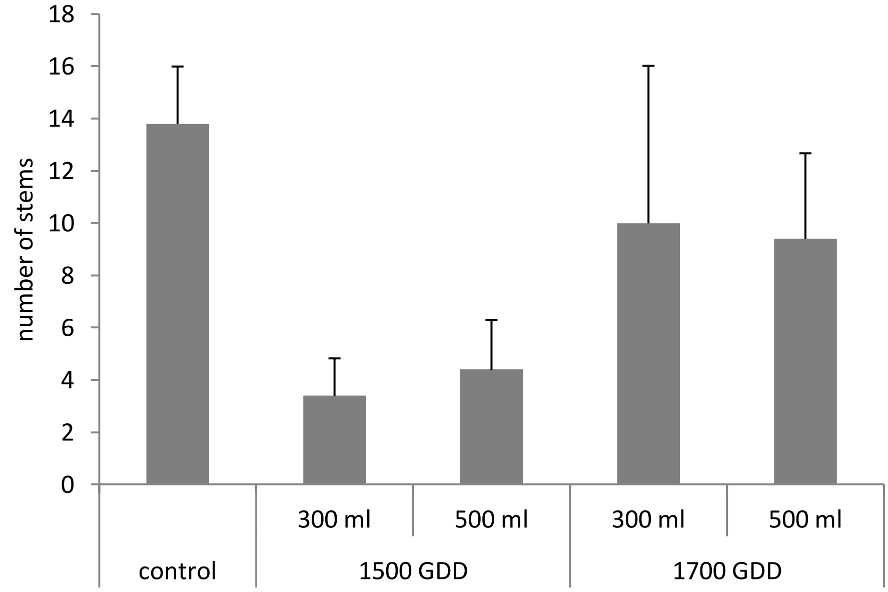

Figure 4. Number of flowering broomrape stems in treatments sprayed with two rates of glyphosate at two timings. No stems were produced by plants sprayed at 1300 GDD. Means + 1SE (*n* = 5). Fewer broomrape stems were produced in 1500 GDD treatments than other treatments (ANOVA, GDD effect p = 0.032)

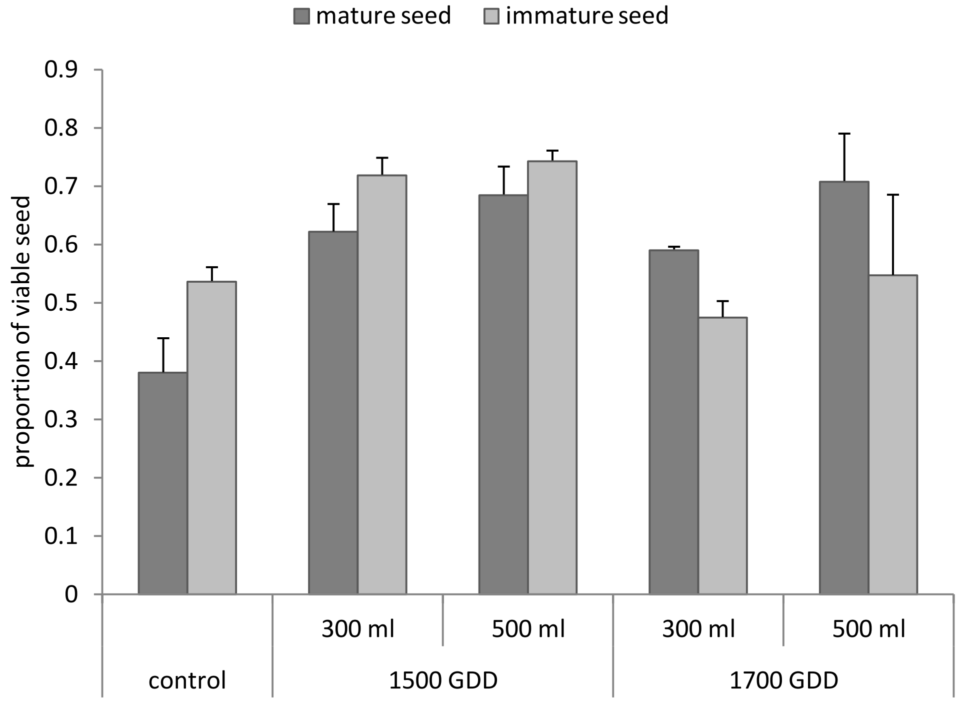

Figure 5. Proportion of viable broomrape seed in treatments sprayed with two rates of glyphosate at two timings and unsprayed controls. Bars are means + 1 SE. Replicate numbers for treatments are from L-R, 5, 3, 3, 3, 5). For mature seed, the 500 ml ha^{-1} treatments at both spray times had a significantly higher proportion of viable seed than controls (ANOVA).

Discussion

The rates of glyphosate applied mostly killed capeweed and cretan weed plants although the early spray at either rate was not sufficient to kill cretan weed. Although hosts were killed, broomrape plants that had emerged when herbicides were applied were still able to develop mature viable seed. Although we observed no broomrape emergence on capeweed hosts it is possible that had these plants been infected by broomrape they could potentially have produced viable seed although the host capeweed died.

Late season glyphosate spraying will only successfully control broomrape when it is applied before broomrape plants flower. Plants sprayed when the broomrape stems were in the bud stage or flowers had just opened did not develop seeds. Plants sprayed when most broomrape flowers were open developed to produce some mature seed. Broomrape plants left to develop until 1700 GDD produced the largest amount of stems and seed indicating that the earlier spray at 1500 GDD probably killed or arrested the development of stems that had not yet emerged.

There were no differences in spray rates.

Broomrape seeds were not killed by application of herbicide to hosts or direct contact of the herbicide with the broomrape plant. It would appear that the herbicide is not transferred to the seed or that the rate is not sufficient to result in seed mortality. Broomrape plants were dead when seeds were collected but were alive when plants were sprayed.

Immature broomrape seed is not able to germinate and with the death of the mother plant it would probably not receive resources to complete development. Provided spraying occurs when mature flowers are absent there should be no production of viable mature seed.

Other studies have shown that best control of broomrape with glyphosate is achieved when hosts are sprayed prior to emergence, during the later stages of broomrape subterranean development as susceptibility to glyphosate varies with broomrape age (Castejon-Munez et al 1990, Mesa-Garcia & Garcia-Torres 1985, Matthews 2002).

Although high rates of glyphosate were found to inhibit broomrape seed germination when applied directly to mature seeds or seed capsules (Hershenhorn et al 1998, Khalaf 1991, Matthews 2004 unpublished data) our study has demonstrated that seed remains viable. In a study by Lins et al (2005) glyphosate applied post-emergence to *O. minor* did not prevent the production of seed that was later able to infect new hosts.

Recommendations

- Glyphosate will not prevent the production of viable broomrape seed if applied post-emergence after broomrape begins flowering.
- Late pre-emergent glyphosate application is more effective for broomrape control than post-emergent application. Ideally, glyphosate should be applied at or before 1300 GDD and before broomrape plants begin emerging. If glyphosate is only applied when broomrape is confirmed as present (*i.e.* post-emergence), this should take place at the first signs of bud emergence or flower opening and before the first flowers finish to prevent the production of viable mature seed.
- A 300 ml ha^{-1} application rate is as effective as a 500 ml ha^{-1} rate.

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8. Broadstrike double applications

John Matthews

CRC for Australian Weed Management, University of Adelaide

Report compiled by Jane Prider

Introduction

Broadstrike has not consistently prevented the emergence of broomrape in volunteer pastures. This trail examines whether an early timing or a double spraying of Broadstrike is as effective as Ally in controlling broomrape.

Methods

Four replicate plots (4m x 5m) of weeds with treatments:

5. Unsprayed controls
6. Ally 5 g ha^{-1} sprayed on 6/6/2006
7. Broadstrike 25 g ha^{-1} sprayed once on 6/6/2006
8. Broadstrike 25 g ha^{-1} sprayed twice on 6/6/2006 and 4/7/2006

Two cores were collected from each plot after the first spray but before the second spray on 26/6/2006 and after the second spray on 30/7/06. The soil was washed from the roots within cores and the number of broomrape attachments were counted. Emerged broomrape were counted over the entire plots.

Results and discussion

No dead attachments were collected from cores, 20 days after the first herbicide spraying (Fig. 1). This indicates that attachments either formed after the spray application or that the absorbed herbicide takes more than 20 days to be taken up, translocated and absorbed by the parasite. Although Ally and one of the Broadstrike treatments have fewer attachments than the controls, the other Broadstrike treatment had more attachments. There is thus not conclusive evidence that the herbicide applications have destroyed or prevented the formation of very early attachments.

By late July attachments had continued to form in the control plots but to a lesser extent in the treated plots (Fig. 1). Dead attachments were detected, although this did not differ significantly from control plots. However, dead attachments may have fallen off before they could be counted. Attachments continued to form in Broadstrike x1 treatments but it appears there are not more attachments occurring in the Ally and Broadstrike x2 plots. It could be concluded that Broadstrike gives less than one month protection when sprayed on these dates.

No broomrape emerged in plots treated with Ally (Fig. 2). Broadstrike treated plots had fewer emerged broomrape than control plots although this difference was not significant. The results indicate that the double spray was more effective than a single spray in suppressing emergence although this experiment does not assess whether a single spray at a later timing would be equally effective.

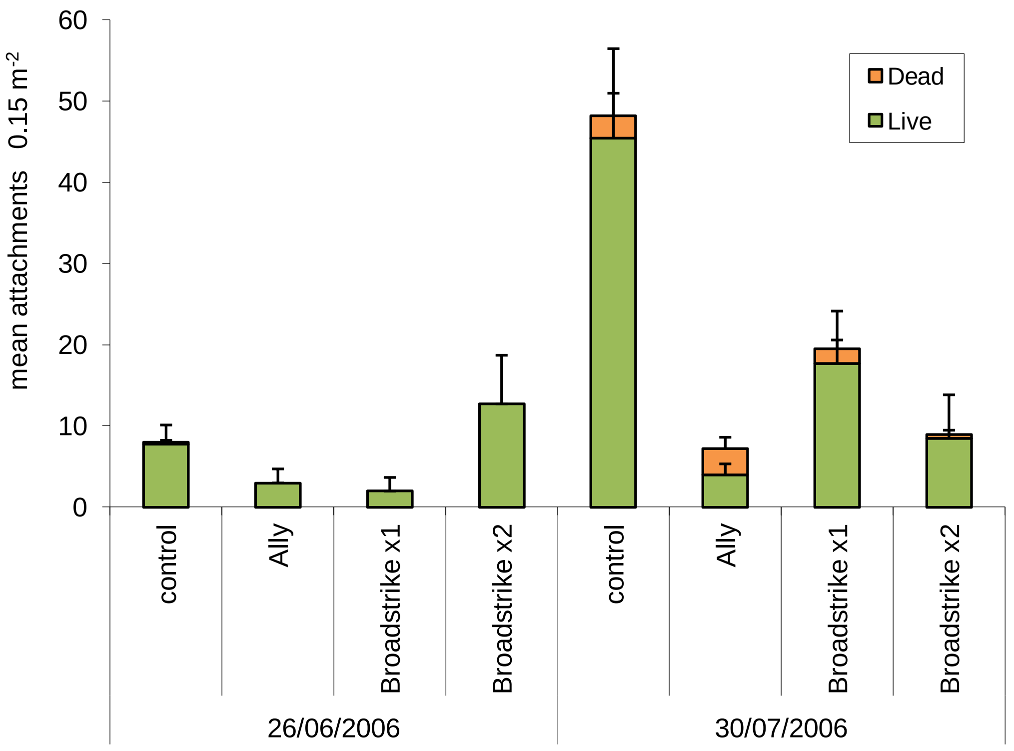

Figure 1. Broomrape attachments on roots retrieved from cores collected from plots on 26/6/2006, 20 days after first herbicide application and on 30/7/2006, 26 days after the second application of Broadstrike to the double-sprayed plots. Bars show mean + SE (*n*=4). Results are pooled for the two cores collected from each plot.

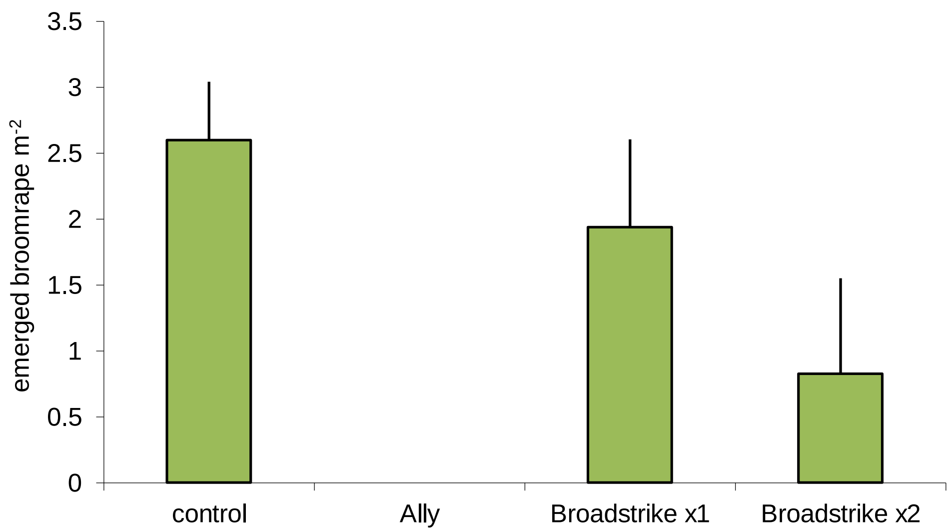

Figure 2. Emerged broomrape counted in plots treated with herbicides. Bars show mean + SE (*n*=4).

9. Timing of herbicide application on cretan weed to kill branched broomrape attachments

Anna Williams and Che DeDear

Branched Broomrape Eradication Program

2006

Aim:

To determine if branched broomrape attachments are killed after application of a sub-lethal herbicide dose to the host, cretan weed.

Materials and methods:

This was a laboratory trial examining herbicide types and timing of application. The five herbicide treatments were:

1. Broadstrike (25g/ha)
2. Ally (3g/ha)
3. Raptor (45g/ha)
4. Logran (7g/ha)
5. Control (water only)

The three timings of application were:

1. When all hosts had attachments
2. 3 weeks after all had attachments
3. 6 weeks after all had attachments

The experiment used the hydrobag method. Cretan weed seedlings were initially grown in pots and transplanted into polybags when they had reached the 2 – 4 true leaf stage. One to two weeks after transplanting the host roots were inoculated with branched broomrape by wiping sterilised broomrape seeds onto the roots.

Hydrobags were placed into tubs in groups of 40. The position of the bags in the tubs was re-randomised every month. Bags were examined regularly and broomrape attachments were circled by marking the bag and the date was recorded when the attachment first appeared. At each spraying up to 5 attachments were randomly selected and broomrape size and health was measured. Host size (# leaves) and health was also recorded. One and three weeks after spraying (two and four for the first herbicide application) any dead marked broomrape plants were recorded and the vigour of the weed was scaled from 1 = healthy (no necrosis) to 5 = dead.

Results

There was a decline in the proportion and health of broomrape tubercles in all treatments, including controls after the earliest spraying (Fig. 1). Decline was greatest in the Raptor and Logran treatments.

Delaying the spraying by a further two weeks produced similar results with a decline in broomrape tubercles in all treatments, including controls (Fig. 2). None of the herbicide treatments reduced tubercle numbers to a greater extent than the reduction in controls.

Following the spraying two weeks later, four weeks after the first attachment were observed, no tubercles survived the Ally treatment but tubercle survival and health in the other herbicide treatments was similar to controls (Fig. 3).

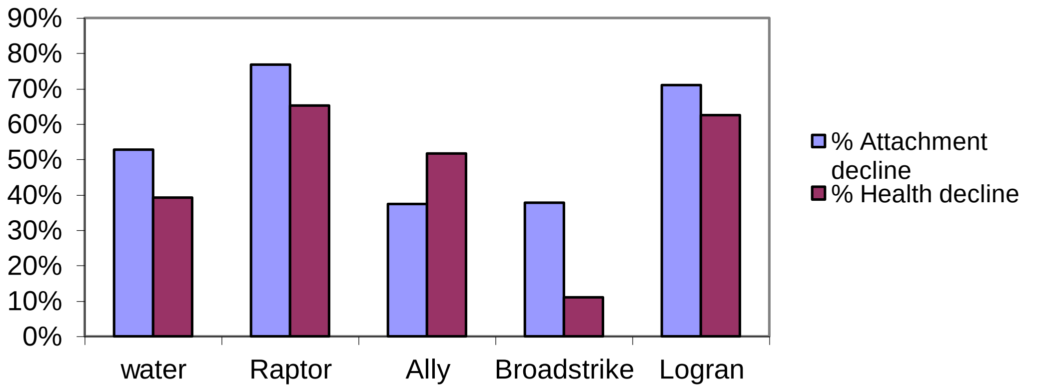

Figure 1. Decline in number and health of broomrape tubercles on cretan weed hosts from 2- 4 weeks after spraying for the first timing, when broomrape tubercles were from 1.3 – 2.5 mm in diameter.

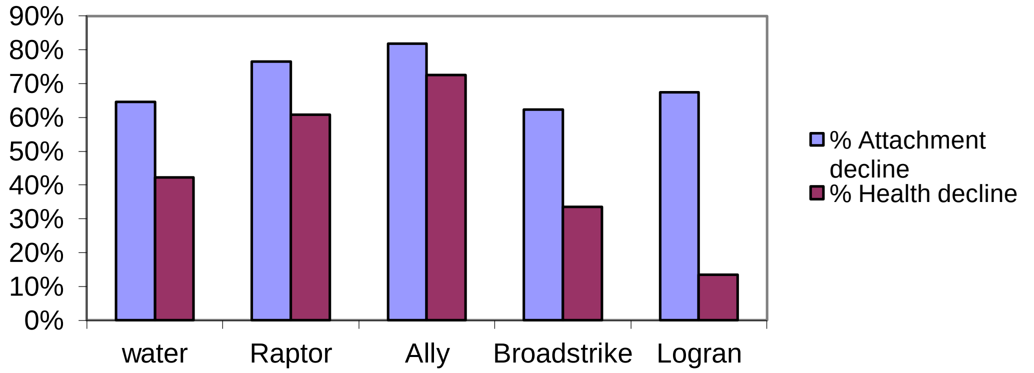

Figure 2. Decline in number and health of broomrape tubercles on cretan weed hosts from 0- 3 weeks after spraying for the second timing (two weeks after the first spraying), when broomrape tubercles were from 13.4 – 18.8 mm in diameter.

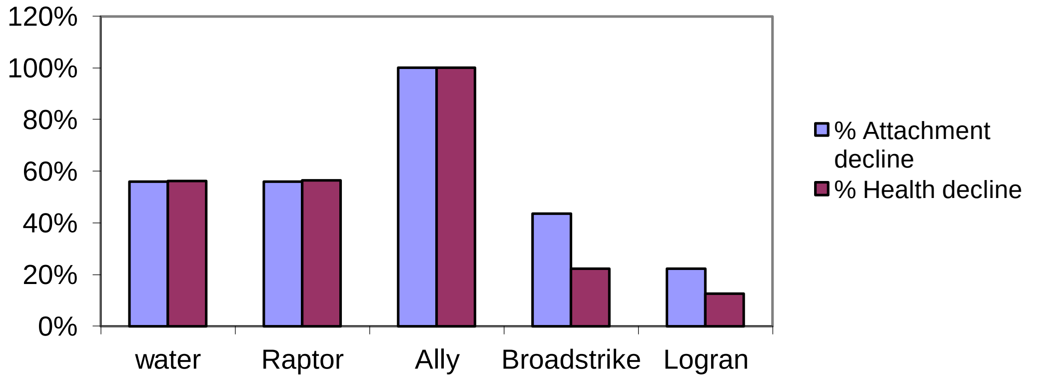

Figure 3. Decline in number and health of broomrape tubercles on cretan weed hosts from 0- 3 weeks after spraying for the second timing (four weeks after the first spraying), when broomrape tubercles were from 16.8 – 23.6 mm in diameter.

10. Broadstrike for control of broomrape in crops

Anna Williams

Branched Broomrape Eradication program

2007

Aim:

This trial tested the efficacy of Broadstrike for the control of broomrape in wheat, canola and pasture.

Method:

The trial was conducted at the Mannum Trial Site. The area was cultivated on 30/4/2007. There were 3 replicate plots sown to wheat, canola, and volunteer pasture on 15/5/2007. The herbicide Broadstrike was applied to one half of each plot on 10/8/2007.
Prior to spraying 5 weed hosts were dug up from each plot and the soil washed to collect broomrape tubercles. This process was repeated after spraying.

Results:

There was no difference in the proportion of infected hosts collected prior to or following spraying with Broadstrike (Fig. 1). The proportion of infected hosts did not differ between sprayed and unsprayed treatments.

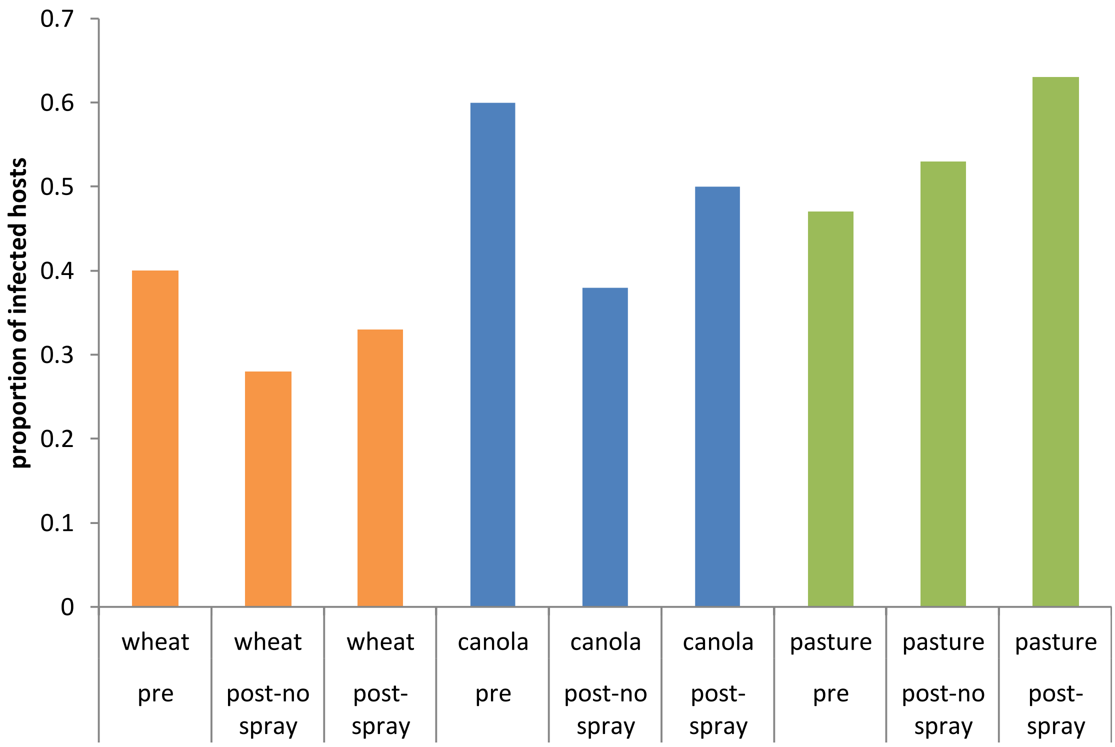

Figure 1. The proportion of sampled host plants that were infected by broomrape, each bar shows the mean from 3 plots.

In canola plots there were fewer broomrape tubercles on hosts in plots following spraying than prior to spraying however hosts form both sprayed and unsprayed plots had similar numbers of tubercles (Fig. 2). Spraying with Broadstrike did not reduce the number of broomrape tubercles on host plants in the wheat and pasture plots.

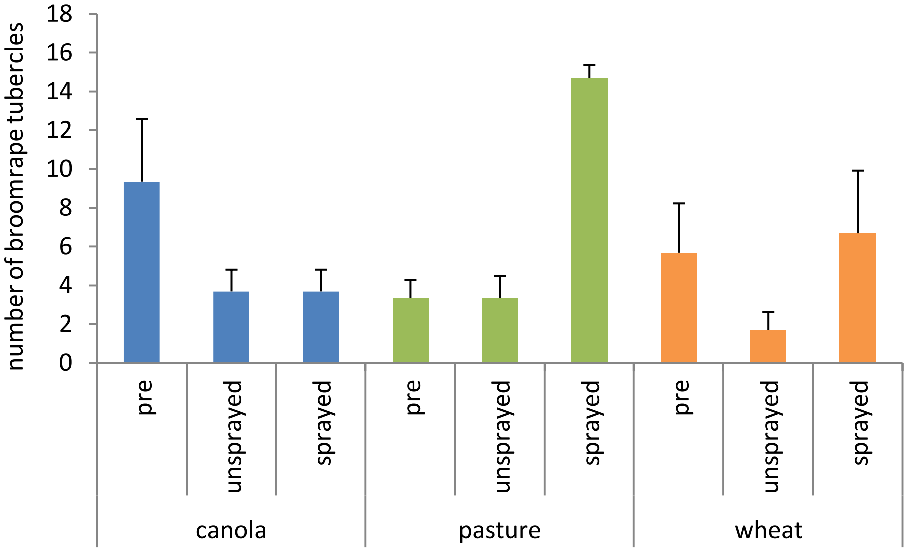

Figure 2. Number of broomrape tubercles summed over 5 host plants collected from each plot. Bars shown mean + 1 SE, n = 3 plots.

11. Effects of herbicides used to control broomrape on hosts in pastures

Keith Bolto and Tamara Rohrlach

Rural Solutions

2009

Analysis by Jane Prider

Trial details not available

Methods

The analysis addressed the following questions

1. Were the herbicide treatments effective at reducing broomrape emergence?
2. Which herbicide treatments reduced the abundance of broomrape hosts?
3. Were there any observable impacts of herbicide treatments on target plants?
4. Did herbicide treatments reduce the yield of medic plants?

There were up to four datasets:

1. Broomrape emergence
2. Host abundance
3. Herbicide damage
4. Dry harvest

For host abundance, counts for the three quadrats for each host species were pooled and converted back to the original quadrat size where this could be determined. The data fitted a negative binomial distribution. A Generalised Linear Mixed Model (GLMM) with a negative binomial family and logarithmic link function was fitted to the data for the factor herbicide treatment, and sampling time (pre or post-spray) as a nested factor within treatment, to account for the lack of independence between sampling times. In the model output, a significant treatment/spray interaction indicates differences in host abundance between plots pre and post-spray. Hosts were analysed separately. Some treatments were removed where they comprised zero values. Where these occurred in post-spray treatments, and there were plants present pre-spray, it can be assumed that there was a significant effect of the herbicide application.

Broomrape emergence was only analysed for regenerating pasture. The data fitted a negative binomial distribution so a Generalised Linear Model (GLM) was fitted for the factor herbicide treatment.

For the herbicide damage analyses, in some cases control values comprised all 100% values were removed from the analyses as they presented problems due to a lack of variance. The data was analysed using ANOVA as data fitted a normal distribution with homogeneous variances. Tests were for differences between herbicide treatments. Where these tests were significant, Tukey HSD tests were used to determine which treatment differences were significant.

Dry harvest data fitted a normal distribution and variances were homogeneous so ANOVA was sued to test for differences between herbicide treatments. Where these tests were significant, Tukey HSD tests were used to determine which treatment differences were significant.

Results

Table 1 provides an overall summary of the negative effects of the herbicide treatments. Details of the individual analyses follows.

Table 1. Summary table of herbicides that had a significant negative effect in pasture varieties. Dashes indicate where responses could not be tested due to missing or insufficient data.

Pasture variety	Herbicide with negative effect						
	Broomrape emergence	Host abundance				Herbicide damage	Dry harvest
		Cape weed	Cretan weed	Turnip	Medic		
Angel medic	-	none	-	Intervix 300 Intervix 500 Logran 7 Logran 15	-	Ally Logran 7 Logran 15 Intervix 500	Ally
Herald medic	-	Early BS Double BS Credit	-	Early BS Double BS Diuron & Agritone Diuron & Agritone & BS	-	None (medic)	none
Clover	-	none	Jaguar Agtyrne	Jaguar Agtyrne Tigrix Raptor	-	none	-
Canola	Intervix 300 Intervix 500	-	-	-	-	-	-
Regenerating pasture	none	none	none	MCPA & Diuron MCPA & Diuron & BS	none	-	-
Triticale	-	Amicide & Lontrel Broadside Bromicide MA	none	Amicide & Lontrel Broadside Bromicide MA MCPA & Diuron Jaguar	-	-	-

Angel medic

Broomrape emergence

Insufficient data for analysis.

Host abundance

CAPE WEED

Spraying had no significant effect on cape weed abundance (Table 2).

Table 2. Results of GLMM, effects of herbicide treatment on cape weed abundance in Angel medic plots. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	2.197	0.527	4.17	<.001
treatment Ally 5	-1.638	0.819	-2.00	0.046
treatment Intervix300	0.000	0.745	0.00	1.000
treatment Intervix500	-0.251	0.751	-0.33	0.738
treatment Logran15	-2.89	1.01	-2.85	0.004
treatment Logran7	-0.405	0.755	-0.54	0.591
treatment Control .spray	-0.118	0.748	-0.16	0.875
treatment Ally 5 .spray	-1.25	1.07	-1.17	0.241
treatment Intervix300 .spray	-0.251	0.751	-0.33	0.738
treatment Intervix500 .spray	0.452	0.747	0.60	0.545
treatment Logran15 .spray	-8.0	23.4	-0.34	0.733
treatment Logran7 .spray	0.154	0.760	0.20	0.839

CRETAN WEED

I analysed this data but due to the absence of plants in most plots, the analysis is not very informative. It did show that spraying was significant but there was no interaction with herbicide treatments. I would say there is not enough data here for analysis although it should be noted that Logran may be effective.

TURNIP

All herbicides apart from Ally (Table 3) reduced turnip numbers (not included in analysis as turnip abundance all zero post-spray).

Table 3. Results of GLMM, effects of herbicide treatment on turnip abundance in Angel medic plots. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference, so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	3.091	0.511	6.05	<.001
treatment Ally 5	-2.079	0.776	-2.68	0.007
treatment Control .spray	0.000	0.723	0.00	1.000
treatment Ally 5 .spray	-1.299	0.961	-1.35	0.177

Dry Harvest

There was a difference in the effect of the herbicides on the dry weight of Angel medic p = 0.011 (Fig. 1). Medic sprayed with Ally had less biomass than controls and Intervix 300 ml treatments. Other comparisons were not significantly different.

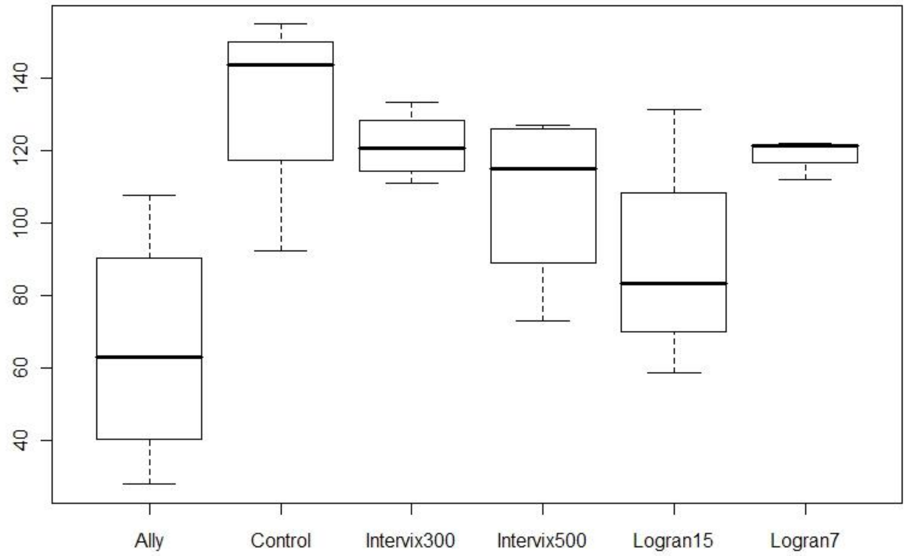

Figure 1. Effect of herbicides on production of dry matter by Angel medic. The horizontal line in each boxplot represents the median.

Herbicide damage

There was a significant difference between herbicide treatments on the condition score of Angel medic (ANOVA, $p < 0.001$).

The means for each treatment were:

Treatment	Mean
Ally	8.75^{a}
Intervix300	80.00^{b}
Intervix500	68.75^{b}
Logran15	30.00^{ac}
Logran7	58.75^{bc}

Values labelled with a different letter were significantly different (Tukey HSD tests).

Herald medic

Broomrape emergence

Insufficient data for analysis

Host abundance

CAPE WEED

Cape weed abundance was lower in plots following herbicide application in early Broadstrike and Credit treatments (not analysed as all zeroes post-spray) and in double Broadstrike treatments (Table 4).

Table 4. Results of GLMM, effects of herbicide treatment on cape weed abundance in Herald medic plots. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	0.916	0.592	1.55	0.121
treatment BS + BS	-2.30	1.26	-1.82	0.069
treatment Diuron & Agritone + BS	-2.30	1.26	-1.82	0.069
treatment Diuron & Agritone + Nil	-1.204	0.966	-1.25	0.213
treatment Nil + BS	-0.105	0.843	-0.12	0.901
treatment Acontrol .spray	0.405	0.816	0.50	0.619
treatment BS + BS .spray	2.48	1.26	1.98	0.048
treatment Diuron & Agritone + BS .spray	1.79	1.29	1.39	0.165
treatment Diuron & Agritone + Nil .spray	0.51	1.02	0.50	0.615
treatment Nil + BS .spray pre	-0.405	0.882	-0.46	0.646

CRETAN WEED

There was not sufficient data for analysis.

TURNIP

The double Broadstrike and both Diuron + Agritone treatments were removed from the analysis as there were none or only one plant remaining in these plots following herbicide application. It can therefore be concluded that these herbicide combinations reduced turnip abundance. Early Broadstrike also had a significant effect on turnip abundance (Table 5).

Table 5. Results of GLMM, effects of herbicide treatment on turnip abundance. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	1.792	0.540	3.32	<.001
treatment BS + Nil	-3.18	1.24	-2.56	0.010
treatment Nil + BS	-0.539	0.783	-0.69	0.491
treatment Nil + Credit	0.460	0.754	0.61	0.542
treatment Acontrol .spray	0.348	0.756	0.46	0.645
treatment BS + Nil .spray	3.81	1.23	3.09	0.002
treatment Nil + BS .spray	1.253	0.769	1.63	0.103
treatment Nil + Credit .spray	-0.054	0.744	-0.07	0.942

Herbicide damage

There was insufficient data for an analysis of cretan weed. It appears that none of the herbicides caused any observable damage to cretan weed plants in comparison to controls. The cape weed data is also problematic due to the unbalanced number of observations in each treatment. Herbicides do not appear to have affected cape weed plants in comparison to controls. There was no difference between condition scores for medic (ANOVA, $p = 0.91$).

Dry harvest

There was no significant difference between the dry weights of Herald medic plants in any of the herbicide treatments (ANOVA, $p = 0.68$).

Canola

Broomrape emergence

There was no emergence in plots where Intervix was applied at 300ml and 500 ml although there was emergence in controls.

Clover

Broomrape emergence

There is not enough data to conduct a meaningful analysis here.

Host abundance

CAPE WEED

There was no effect of herbicide spraying on the abundance of cape weed (Table 6).

Table 6. Results of GLMM, effects of herbicide treatment on cape weed abundance in clover plots. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	0.693	0.612	1.13	0.257
treatment Agtyrne	-0.981	0.979	-1.00	0.316
treatment Jaguar	-2.08	1.27	-1.63	0.103
treatment Raptor	0.118	0.856	0.14	0.890
treatment Tigrex	-0.288	0.889	-0.32	0.746
treatment Control .spray	-0.470	0.908	-0.52	0.605
treatment Agtyrne .spray	0.847	0.988	0.86	0.391
treatment Jaguar .spray	1.61	1.30	1.23	0.217
treatment Raptor .spray	-0.252	0.865	-0.29	0.771
treatment Tigrex .spray	0.000	0.912	0.00	1.000

CRETAN WEED

The abundance of cretan weed in plots treated with Jaguar was significantly different to controls (Table 7). Agtyrne also reduced cretan weed abundance (due to the zero values in the post-treatment it was not included in the analysis).

Table 7. Results of GLMM, effects of herbicide treatment on cretan weed abundance in clover plots. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	1.609	0.547	2.94	0.003
treatment Jaguar	-3.00	1.24	-2.41	0.016
treatment Raptor	-0.223	0.782	-0.29	0.775
treatment Tigrex	-1.897	0.940	-2.02	0.043
treatment Control .spray	0.182	0.769	0.24	0.813
treatment Jaguar .spray	3.26	1.24	2.63	0.009
treatment Raptor .spray	0.061	0.788	0.08	0.939
treatment Tigrex .spray	1.609	0.949	1.70	0.090

TURNIP

Turnip abundance was significantly lower compared to controls in plots sprayed with Raptor, Agtyrne, Jaguar and Tigrex (Table 8). Tigrex data were not included in analysis due to all zero values post-spray.

Table 8. Results of GLMM, effects of herbicide treatment on turnip abundance in clover plots. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	3.458	0.508	6.81	<.001
treatment Agtyrne	-3.235	0.841	-3.84	<.001
treatment Jaguar	-3.235	0.841	-3.84	<.001
treatment Raptor	-1.666	0.741	-2.25	0.025
treatment Control .spray	0.309	0.717	0.43	0.666
treatment Agtyrne .spray	3.281	0.841	3.90	<.001
treatment Jaguar .spray	3.497	0.840	4.16	<.001
treatment Raptor .spray	1.720	0.741	2.32	0.020

Herbicide damage

There is not enough data to make any meaningful comparisons for the two weed species. For clover, I removed the controls from the analysis. There was no significant difference between herbicide treatments (ANOVA, p = 0.359). Unfortunately with this analysis I cannot test whether these values are different from the controls. Given that Agtyrne was not significantly different from Raptor, the treatments were possibly not different from the controls (see table of means below).

Treatment	Mean
Agtyrne	57.50
Control	100.00
Jaguar	80.00
Raptor	95.00
Tigrex	65.00

Regenerating pasture

Broomrape emergence

There was no significant difference in broomrape emergence between herbicide treatments and controls (Table 9).

Table 9. Results of GLM, effects of herbicide treatment on broomrape emergence in regenerating pasture plots.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	2.175	0.472	4.61	<.001
treatment AFA	0.870	0.696	1.25	0.212
treatment Credit	-11.9	38.6	-0.31	0.759
treatment MD	-1.163	0.751	-1.55	0.121
treatment MDB	-11.9	44.6	-0.27	0.790

Host abundance

CAPE WEED

There was no difference between herbicide treatments in cape weed abundance following spraying (Table 10).

Table 10. Results of GLMM, effects of herbicide treatment on cape weed abundance in regenerating pasture plots. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	1.012	0.584	1.73	0.083
treatment Agtyrne	0.000	0.826	0.00	1.000
treatment Jaguar	1.157	0.787	1.47	0.141
treatment Raptor	0.167	0.817	0.20	0.838
treatment AControl .spray	0.898	0.792	1.13	0.257
treatment Agtyrne .spray	0.087	0.821	0.11	0.916
treatment Jaguar .spray	-0.154	0.750	-0.21	0.837
treatment Raptor .spray	0.961	0.779	1.23	0.217

CRETAN WEED

There was no difference between herbicide treatments in cretan weed abundance following spraying (Table 11).

Table 11. Results of GLMM, effects of herbicide treatment on cretan weed abundance in regenerating pasture plots. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	2.110	0.529	3.99	<.001
treatment Agtyrne	0.614	0.739	0.83	0.406
treatment Jaguar	-0.129	0.752	-0.17	0.863
treatment Raptor	-0.606	0.765	-0.79	0.428
treatment AControl .spray	-0.932	0.779	-1.20	0.232
treatment Agtyrne .spray	-0.556	0.738	-0.75	0.452
treatment Jaguar .spray	0.622	0.744	0.84	0.403
treatment Raptor .spray	0.329	0.772	0.43	0.670

MEDIC

There was no difference between herbicide treatments in medic abundance following spraying (Table 12).

Table 12. Results of GLMM, effects of herbicide treatment on medic abundance in regenerating pasture plots. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	1.386	0.559	2.48	0.013
treatment Agtyrne	-0.134	0.796	-0.17	0.867
treatment Jaguar	-1.163	0.873	-1.33	0.183
treatment Raptor	0.363	0.778	0.47	0.641
treatment AControl .spray	-0.288	0.804	-0.36	0.720
treatment Agtyrne .spray	-0.847	0.859	-0.99	0.324
treatment Jaguar .spray	1.281	0.869	1.47	0.141
treatment Raptor .spray	-1.344	0.843	-1.59	0.111

TURNIP

There were significant differences in turnip abundance following spraying with MCPA + Diuron and MCPA + Diuron + Broadstrike (not included in analysis as zero plants in plots following spraying). There was no reduced turnip abundance in turnip plots with Credit applied (Table 13).

Table 13. Results of GLMM, effects of herbicide treatment on turnip abundance in regenerating pasture plots. Significant "spray" interaction term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	1.447	0.556	2.60	0.009
treatment T2 Credit	-0.754	0.826	-0.91	0.362
treatment Control .spray	0.111	0.781	0.14	0.887
treatment T2 Credit .spray	-0.288	0.889	-0.32	0.746

Triticale

Broomrape emergence

Insufficient data for analysis

Host abundance

MEDIC

Insufficient data for analysis

TURNIP

All herbicides reduced the abundance of turnip (data not analysed as mostly zero values in post-spray sampling).

CAPE WEED

Amicide + Lontrel, Broadside, and Bromicide MA plots had mostly no cape weed plants following spraying. There were not enough plants in other treatments for analysis.

CRETAN WEED

Jaguar, Amicide + Lontrel, and Bromicide MA plots had no or few plants pre-spray, so data could not be analysed. MCPA + Diuron and Broadside had no significant effect on cretan weed abundance. The abundance of cretan weed increased in control plots (Table 14).

Table 14. Results of GLMM, effects of herbicide treatment on cretan weed abundance in triticale plots. Significant interaction "spray" term indicates herbicide application reduced host numbers, control as reference so p-values indicate difference to controls.

Parameter	estimate	s.e.	t(*)	t pr.
Constant	1.981	0.533	3.71	<.001
treatment Broadside	-3.37	1.24	-2.72	0.007
treatment MCPA + Diuron	-1.576	0.837	-1.88	0.060
treatment control .spray	-3.37	1.24	-2.72	0.007
treatment Broadside .spray	1.79	1.29	1.39	0.165
treatment MCPA + Diuron .spray	0.288	0.889	0.32	0.746

12. Broadstrike and Intervix timing trial

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March 2010

Aim

To determine the optimum timing (in terms of growing degree days) for using Broadstrike and Intervix to prevent broomrape emergence in a weedy pasture situation.

Introduction

Broadstrike is commonly used for the control of broomrape in medic pastures. It has two methods of preventing broomrape emergence:

- Host denial
- Translocation to attachments

If sprayed early, a percentage of broadleaf weed hosts will be killed, reducing the chance of broomrape emergence by reducing the number of host plants. Later applications of Broadstrike will kill attachments but not the host. It is assumed Broadstrike gives around two weeks protection from broomrape emergence when applied late. There are still many unknowns as to what effect Broadstrike has on attachments, how much protection can be expected from a Broadstrike application and the best timing of the herbicide to prevent emergence.

Intervix is a new imidazolinone group B herbicide used in Clearfield Canola. It also has some application in Angel medic pastures and may be an alternative to using Broadstrike or Ally in weedy pastures. Similar questions need to be answered with Intervix, including identifying the lowest rates possible to achieve good residual broomrape control. Intervix needs to be trialled at two rates and similar effects on broomrape attachments needs to be observed.

This trial was conducted at the Brinkley trial site, which has an excellent density of cretan weed, which is the main host species. Testing these herbicides at this site eliminated the need to have a separate cretan weed trial, and gave a greater understanding on the effect that these herbicides have on broomrape attachments hosting on cretan weed.

The objectives were:

- To identify the best Growing Degree Day timing for applying Broadstrike and Intervix in a weedy pasture.
- To identify the effect that Broadstrike and Intervix have on broomrape attachments to cretan weed at different timings.
- To use broomrape attachments to identify the length of residual activity that can be expected from Broadstrike and Intervix.

Methods

Experiment design

A replicated spray trial including control plots was established at the Brinkley Trial Site in an area known to have thick densities of broomrape and cretan weed. Plots measured 25 m by 4 m.

The herbicide treatments were:

- Broadstrike 25 g ha^{-1} + Uptake
- Broadstrike 25 g ha^{-1} + Bonza
- Intervix 300 ml ha^{-1}
- Intervix 500 ml ha^{-1}
- Ally 5 g ha^{-1}
- Control (no herbicides)

Spray treatments were applied at 500, 750, 1000, and 1250 GDD. Each combination of herbicide treatment and timing was replicated 4 times, giving a total of 96 plots.

Sampling design

Initial sampling of control plots at 800 GDD revealed no attachments, therefore it was decided that attachments would only be sampled from the Broadstrike + Uptake treatments and the controls. This herbicide treatment is considered to be the least effective at BB control and will therefore give the most conservative estimate of herbicide effects on BB attachments. For the other herbicide treatments, attachment time will be assessed by extrapolating GDD backwards from emergence dates.

For sampling attachments, 20 host plants were randomly selected from Broadstrike + Uptake and control plots. These plants and attachments were excavated, soil washed out in the field, bagged and attachments assessed in the lab. Attachments were sampled at approximately 500 GDD intervals following herbicide treatment and at the end of the experiment at 2000 GDD (Table 1).

Table 1. Sampling schedule for attachments

Spray treatment	500 GDD	750 GDD	1000 GDD	1250GDD
Attachment sampling	1000 GDD			
		1250 GDD		
	1500 GD		1500 GDD	
		1750 GDD		1750 GDD
	2000 GDD	2000 GDD	2000 GDD	2000 GDD

This sampling interval is based on the following:

- If the herbicide has killed attachments then it will take at least 360-400 GDD (500 GDD – conditioning period) for new attachments to form and any attachments present will therefore be much smaller than controls collected at the same time
- If the herbicide has killed attachments and has residual effects of up two weeks or more there will be no attachments present (500 GDD – conditioning period of two weeks + two weeks residual herbicide effects)
- If the herbicide has not been effective the attachments will be of similar size to the controls

In the lab, the number and size of attachments on each host was recorded.

Emergence of broomrape plants was recorded for each plot at least weekly after emergence started and plants removed as they emerged (so they were not recounted). The density of host plants was visually estimated in each plot at the end of the experiment.

Analysis

Very few attachments were sampled from plots therefore only the emergence data is reported and used for statistical analyses.

An initial analysis found significant differences between herbicide treatments and the timing of their application on the emergence of broomrape. Although charts of the data indicated that broomrape emergence appeared to be influenced by the timing of application, which was inconsistent between herbicides, the variability between replicates reduced the power of statistical tests to detect any significant interaction. When the experiment was planned it was recognised that broomrape emergence in the previous season increased in density across the site from west to east. Four blocks (replicates) were established across areas from highest broomrape density to lowest density (Fig. 1). This blocking factor was not included in the initial data analysis. The inclusion of this term removes the between block error from the residual variance thus increasing the precision of the analysis.

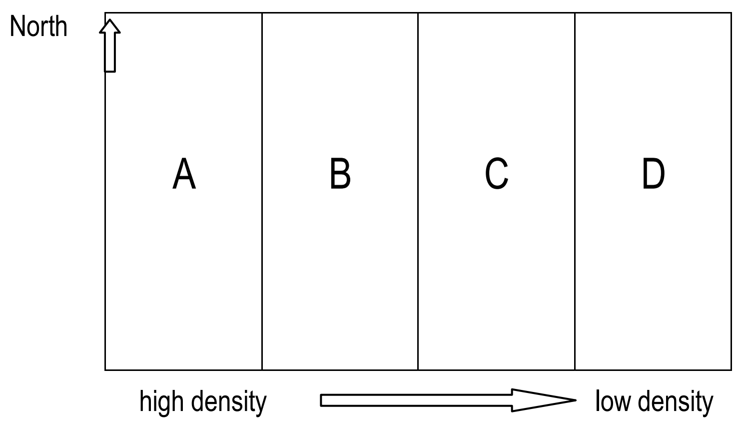

Figure 1. Experimental blocks - all herbicide treatments and application times were included once within each block (*i.e.* no replication within blocks).

The data analysis addressed two questions:

1) Which herbicide provides the best control of broomrape emergence?

2) Is herbicide efficacy influenced by the timing of application?

We used the variable of total broomrape emergence summed over all sampling weeks. A negative binomial model provided the closest fit to the data set that had a very strong right skew. As the data set included many zero values it was not possible to transform the data to fit a parametric (normal) distribution.

Generalized Linear Models (GLM) with a negative binomial family and a log link function, with the factors block, herbicide treatment and timing of application (GDD) and their interactions were fitted to the emergence data. We initially fitted the full model with all interaction terms, with the exception of the three-way interaction between block, treatment and GDD that could not be fitted. To determine which factors in the model were significant, we used an iterative backward elimination procedure, sequentially removing each model term and analysing the residual deviance for each successive model fit (analysis of deviance).

The difference between the residual deviances for any two models of interest was tested using a chi-square test with the appropriate degrees of freedom.

The Broadstrike data were also tested separately in the same manner, in this case assessing the difference between the two formulations Uptake and Bonza which have different adjuvants but the same active ingredient. We also reanalysed these data using log-transformed emergence values, $y = \ln(x + 1)$. This reduced the influence of the extreme emergence values that occurred in some of the blocks. We fitted a Generalised Linear Model (GLM) with normal distribution and an identity link function with model reduction and testing as described above but using F-tests rather than chi-squared tests.

We also analysed the Intervix data separately using negative binomial GLMs as described above. In this case, treatment effects compared the two application rates.

We used Genstat (Version 9.0.0.147) and R (Version 2.8.0) software for the analyses.

Results

The minimal adequate model that described the data included the main effects block, treatment and GDD and the interactions GDD/block and GDD/treatment (Table 1).

The interaction between Block and Treatment was not significant, i.e. the difference between blocks was consistent between treatments. Broomrape emergence was highest in Block A, on the western side of the site, declined in Block B, was almost absent from Block C and was present in low numbers in Block D (Fig. 2). This pattern occured in the control plots as well as the treatment plots and was consistent with density patterns of broomrape observed at the site in 2008.

Table 1. Residual deviances for GLM negative binomial model fit of total broomrape emergence data on the full data set. P-values are results of chi-square tests comparing each successive model. If there is no significant difference ($p > 0.05$) between a model when a term is removed with the previous model then the model with fewer terms is accepted. M2 (shaded) is the minimal model that provides the best fit to the data on that criterion.

Model	Model terms	Terms removed	Residual deviance	Degrees of freedom	P value
M1	Block + Treatment + GDD + (Block/Treatment) + (GDD/Treatment) + (GDD/Block)	-	29.30	45	-
M2	Block + Treatment + GDD + (GDD/Block) + (GDD/Treatment)	Block/Treatment	53.13	60	0.07
M3	Block + Treatment + GDD + (GDD/Treatment)	GDD/Block	70.21	69	0.047
M4	Block + Treatment + GDD	GDD/Treatment	114.4	84	0.007
M5	Block + GDD	Treatment	252.8	89	<0.001
M6	Block	GDD	254.1	92	0.729

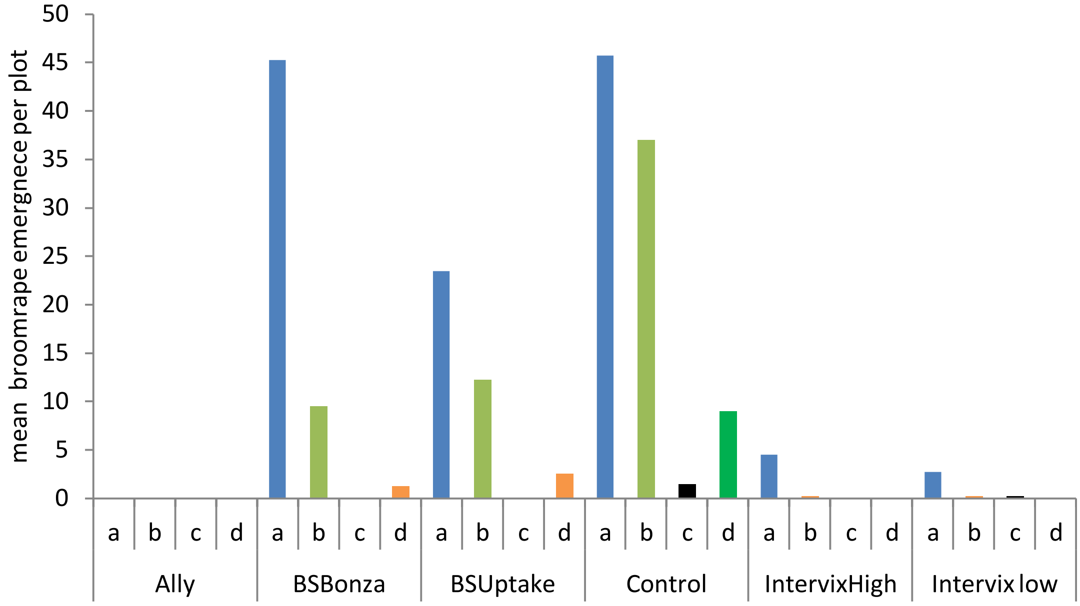

Figure 2. Mean broomrape emergence in herbicide treatment plots across four blocks, *n* = 4. The interaction was not significant.

The effect of timing of herbicide application on broomrape emergence was not consistent across blocks (GDD/Block interaction, Table 1). There was a pattern of increasing broomrape emergence with GDD in Block A but not in the other blocks (Fig. 3). As Fig. 2 shows, most of the plants in Block B were in the control plots and there were consistent low numbers of broomrape in Blocks C and D.

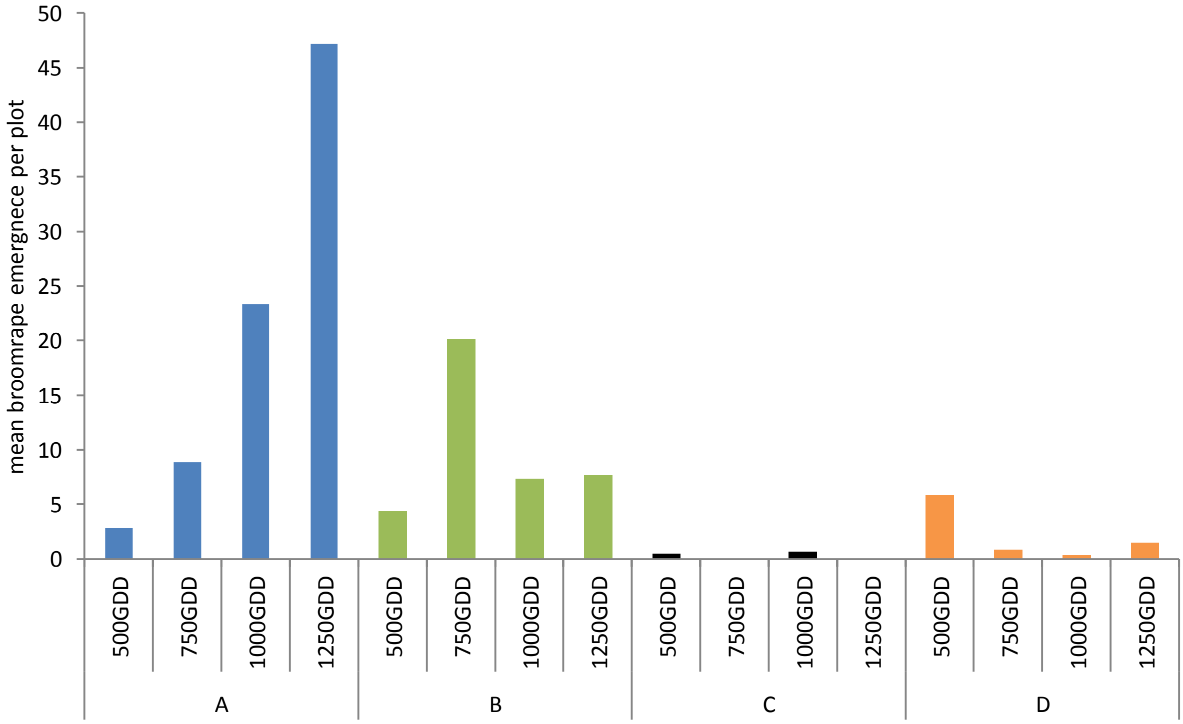

Figure 3. Mean broomrape emergence in GDD plots across four blocks averaged across all treatments, *n* = 6.

The interaction of most interest is between GDD and treatment. The effect of spraying time was not consistent across herbicide treatments (Table 1). For the application of Ally and Intervix, timing had no effect on broomrape emergence (Fig. 4, Intervix data analysed separately). Ally and Intervix reduced broomrape emergence to a greater extent than Broadstrike. There was no emergence in Ally plots and very low emergence in plots sprayed with Intervix. However, the timing had an effect on emergence in Broadstrike treated plots.

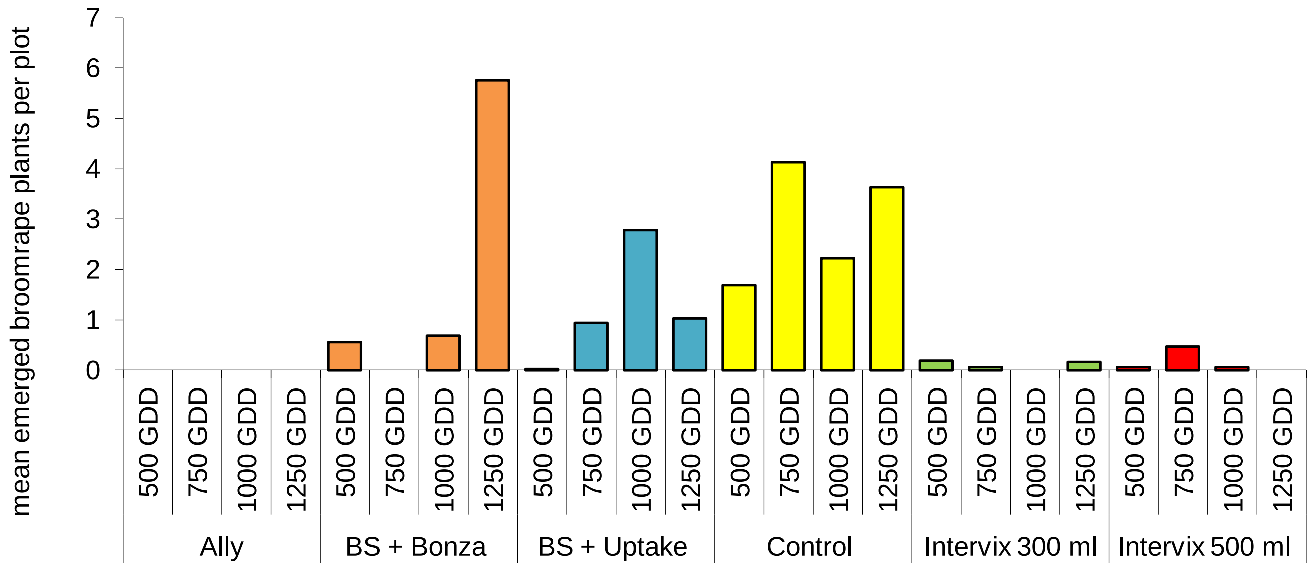

Figure 4. Mean broomrape emergence in plots where herbicide has been applied at different times, *n* = 4, blocks have been pooled.

Broadstrike

The minimal adequate model that described the fit between broomrape emergence and Broadstrike application included the main effects block, adjuvant treatment, GDD and the interaction GDD/treatment (Table 2). Timing of Broadstrike application had a significant effect on broomrape emergence but this depended on which adjuvant was used (GDD/Treatment interaction, Table 2). These differences were consistent across blocks (block interaction terms not significant, Table 2).

Table 2. Residual deviances for GLM negative binomial model fit of total broomrape emergence data to the Broadstrike data. Model M3 (shaded) provides the best fit for the data (see Table 1 for explanation).

Model	Model terms	Term removed	Residual deviance	df	P value
M1	Block + GDD + Treatment +(Block/Treatment) + (GDD/Treatment) + (GDD/Block)	-	12.33	9	-
M2	Block + Treatment + GDD + (GDD/Block) + (GDD/Treatment)	Block/treatment	12.76	12	0.932
M3	Block + Treatment + GDD + (GDD/Treatment)	Block/GDD	26.02	21	0.151
M6	Block + Treatment + GDD	GDD/Treatment	45.26	24	<0.001
M7	Block + GDD	Treatment	45.35	25	0.764
M9	Block	GDD	56.65	28	0.01

There is considerable variation in the data (Fig. 5). The chart indicates that Broadstrike plus Uptake was effective only when applied at 500 GDD. Broadstrike plus Bonza was more effective when applied before 1250 GDD but there was no difference between applications before 1250 GDD.

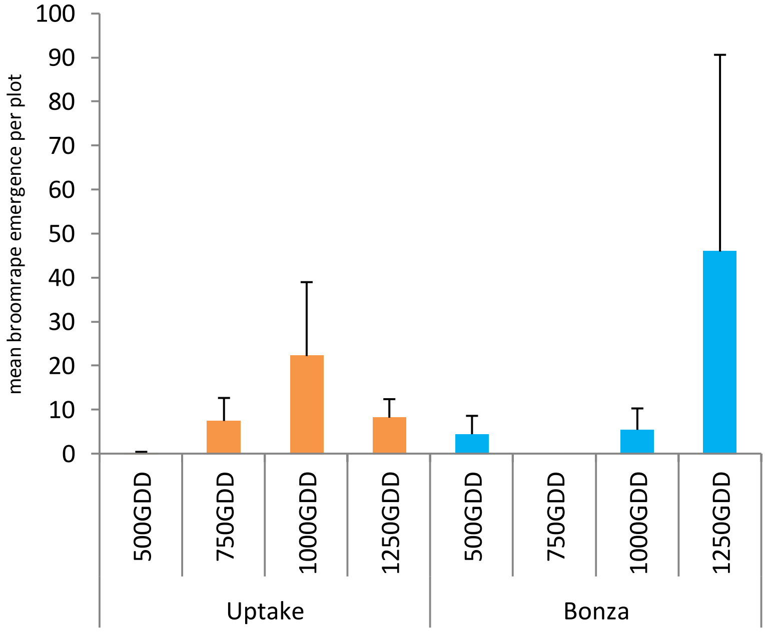

Figure 5. Mean broomrape emergence at different application times for Broadstrike with the adjuvant Upatke or Bonza. Bars show mean ± 1 SE.

In order to reduce the variance, and hence the influence of the blocks that had large numbers of emerged plants, the data were log-transformed and the analysis rerun. The minimal model that fitted this data set included the main effects block and GDD (all other factors and interactions not significant, Table 3). There is a linear trend between application time and broomrape emergence (Fig. 6). Multiple comparison tests or contrasts did not have the power to detect any significant difference between the different levels of GDD. Given the GLM model detected a significant GDD effect, we can conclude that at least the difference between 500 GDD and 1250 GDD is significant.

Table 3. Residual sums of squares and degrees of freedom from fits of GLMs to the log-transformed emergence variables for the Broadstrike data. The GDD term is significant therefore must remain in the model, so M5 (shaded) is the minimal model with the best fit. See Table 1 for explanation.

Model	Model terms	Term removed	Residual SS	df	P
M1	Block + GDD + Treatment +(Block /Treatment) + (GDD/Treatment) + (GDD/Block)	-	15.56	9	-
M2	Block + Treatment + GDD + (GDD/Block) + (GDD/Treatment)	Block/Treatment	16.15	12	0.659
M3	Block + Treatment + GDD + (GDD/Block)	GDD/Treatment	21.97	15	0.767
M4	Block + Treatment + GDD	GDD/Block	37.60	24	0.194
M5	Block + GDD	Treatment	38.79	25	0.412
M6	Block	GDD	46.35	28	0.039

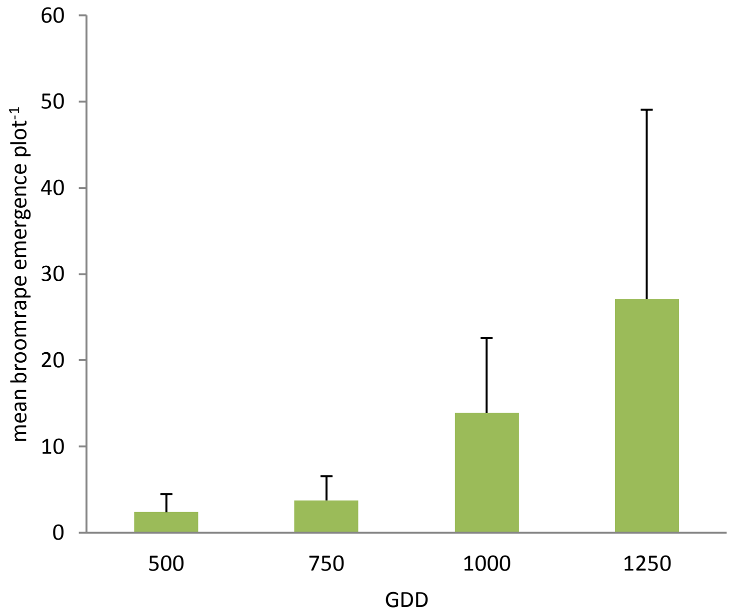

Figure 6. Broomrape emergence at different times of application of Broadstrike, data for two adjuvants pooled. Bars are means ± 1 SE.

Intervix

The Intervix data was analysed separately. There were no significant differences between application rates (treatment) or their timing (GDD) (Table 4).

Table 4. Residual deviances and degrees of freedom from fits of GLMs to the emergence variables for the Intervix data. P-values are results of chi-square tests comparing each successive model (see Table 1 for explanation). M6 (shaded) is the minimal model.

Model	Model terms	Term removed	Residual deviance	df	P
M1	Block + GDD + Treatment +(Block/Treatment) + (GDD/Treatment) + (GDD/Block)	-	0.00001	9	-
M2	Block + Treatment + GDD + (GDD/Block) + (GDD/Treatment)	Block/Treatment	0.8061	12	0.848
M3	Block + Treatment + GDD + (GDD/Treatment)	GDD/Block	6.299	21	0.789
M4	Block + Treatment + GDD	GDD/Treatment	13.46	24	0.067
M5	Block + GDD	Treatment	13.47	25	0.920
M6	Block	GDD	18.3	28	0.184

Weekly emergence

A chart of weekly emergence does not indicate any difference in emergence rates of broomrape in Broadstrike plots in comparison with control plots (Fig. 7).

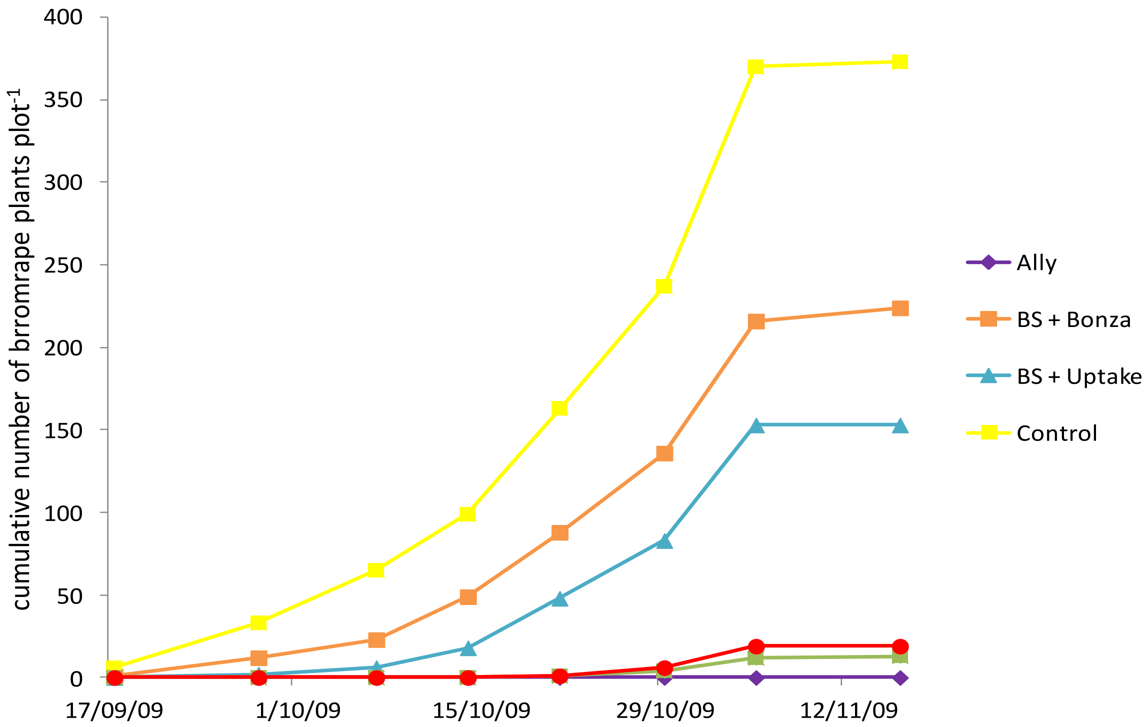

Figure 7. Weekly emergence of broomrape in plots sprayed with different herbicide treatments (pooled across GDD).

Discussion

Ally and Intervix provided more effective control over broomrape emergence than Broadstrike. The timing of application of Ally and Intervix had little influence on their effectiveness. However, for Broadstrike, the data supports earlier application times over later times. After applying analysis methods to decrease the variability in the data, we found a significant linear relationship between the timing of application and broomrape emergence. There is still considerable variation in the data so that the differences between different application times were not significant when pairwise comparison tests were used.

Broadstrike timing deserves further research, using methods that decrease the variation between treatments. Given that there is a potential linear relationship between timing and emergence then increasing the levels of timing treatments will enable this to be tested. Controlling variation by conducting the experiments in pots will increase our ability to detect treatment effects. Of course, this will sacrifice the ability to apply herbicides under more realistic conditions to numbers of host plants that are likely to be encountered in the field. Pot experiments will also enable us to examine the effects of herbicides on attachments. Although this experiment endeavoured to sample attachments, as there were low broomrape numbers in most plots few attachments were collected. It is not clear how Broadstrike affects attachments, whether these effects persist for some time after application, and whether more mature hosts translocate less herbicide than actively growing young hosts. These questions are important if we are to understand how the timing of Broadstrike application affects broomrape.

13. Broadstrike timing for branched broomrape control

Jane Prider, Andrew Craig

Branched Broomrape Eradication Program

December 2010

Summary

Broadstrike® is one of the preferred selective herbicides for use on pastures in the branched broomrape quarantine area. Repeated failures of this herbicide to prevent broomrape emergence has prompted work to refine application practices. In particular, its efficacy for the control of cretan weed or broomrape on this host has long been questioned. In these experiments we assessed the effects of Broadstrike on cretan weed in a series of pot experiments where different rates of Broadstrike were applied singly or in double doses to cretan weed plants of different maturity. Broadstrike had no significant effect on the growth or survival of cretan weed applied at the 4-6 leaf or 8-12 leaf stage of development. Double doses applied four weeks apart also had no significant effect on growth. A dose curve analysis shows that the current rate of 25 g ha^{-1} has a maximum effect on cretan weed growth (albeit not statistically significant) and increasing the rate will not provide better control.

The efficacy of Broadstrike for the control of broomrape on turnip weed, cape weed and cretan weed was assessed in pot experiments in the field at Mannum. We trialled Broadstrike at 25 g ha^{-1} applied at 500, 750, 1000 or 1250 GDD and split applications of 15 and 20 g ha^{-1} applied at 500 and 1000 GDD. There was no broomrape emergence in turnip weed sprayed with Broadstrike at any time and the herbicide killed turnip weed when applied at 500 GDD at the three rates. Cape weed was not killed by Broadstrike and broomrape emergence occurred in plants that were sprayed at 500 GDD but not at other timings or split applications. For cretan weed, Broadstrike only prevented broomrape emergence when sprayed at 1250 GDD. There was no difference in the number of dead broomrape tubercles between treatments indicating that the herbicide was probably not being translocated in cretan weed to affect attached broomrape. Although there were fewer live broomrape on plants sprayed at 1250 GDD and with split applications of 20 g ha^{-1}, these treatments had non-emergent but mature broomrape. These broomrape plants could have emerged given the continual survival of hosts.

In conclusion, Broadstrike was found to have no significant effect on cretan weed growth and survival and although a temporary reduction in growth may slow broomrape development, the herbicide cannot be reliably used for control of broomrape when sprayed at any time. Broadstrike can be used to control broomrape on turnip weed and cape weed. Applications from 750 GDD are recommended to prevent broomrape emergence on both weeds although earlier application will provide control on turnip weed.

Introduction

Group B or acetolactate synthase (ALS) inhibiting herbicides, have proven to be very effective for the control of broomrape in crops internationally (Garcia-Torres and Lopez-Granados 1991; Garcia-Torres *et al.* 1994) and in the Branched Broomrape Quarantine Area (Matthews *et al.* 2006; Matthews 2002). Broomrape is susceptible to many of the systemic Group B herbicides as the active ingredient is translocated to the parasite via the host roots where it can accumulate (Diaz-Sanchez *et al.* 2002; Jurado-Exposito *et al.* 1999). Plants with herbicide tolerance are able to rapidly metabolise the herbicide before it has any toxic effects although the herbicide may still be absorbed and translocated (Cole *et al.* 1989; Mekki and Leroux 1995; Shaner and Robson 1985; Wilcut *et al.* 1988). Therefore the herbicide may have toxic effects on broomrape in the absence of observed effects on the host.

Broadstrike (a.i. flumetsulam) is one of the preferred selective Group B herbicides for use on pastures in the containment area due to the tolerance of some pasture legume species, especially medic. This herbicide is not as consistently effective for the control of *O. ramosa* as other Group B herbicides currently in use (Matthews *et al.* 2006). Seasonal differences that affect the growth of the parasite and host partly explain this variation but the herbicide is also less effective where there is a high proportion of cretan weed (Matthews 2005). Broadstrike may only provide a short period of protection from broomrape infection, especially if cretan weed is herbicide-tolerant and rapidly metabolises flumetsulam. Timing of application is therefore important in these situations, particularly if cretan weed tolerance differs with plant size. Split or double applications may be necessary to provide effective or continued protection from broomrape infection.

Currently, farmers in the quarantine area are advised to apply Broadstrike at 1000 GDD as our life cycle modelling has shown that this is when most broomrape attachments will be present. However, Group B herbicides can be less effective at high parasite loads (Eizenberg *et al.* 2009; Sauerborn *et al.* 1989), when broomrape has a well developed subterranean stem or has emerged (Garcia-Torres *et al.* 1995; Plakhine *et al.* 2001; Sauerborn *et al.* 1989). Our Broadstrike timing experimental results are variable. In field trials with Broadstrike in 2009, there were fewer emerged *O. ramosa* in plots treated at 500 GDD than at 1250 GDD. Differences in emergence at 750 GDD and 1000 GDD were not significant although high variability in the field plots reduced the power of statistical tests to detect differences. Early Broadstrike applications were more effective than late applications in 2004 in medic pastures but Broadstrike was not effective in vetch (Matthews *et al*. 2005) nor in 2006 trials in plots with cape weed and cretan weed (Matthews *et al.* 2006). Early and late applications were effective in medic pasture trials under the dry seasonal conditions of 2008 (Matthews 2008) although the density of cretan weed in these trials is not known.

Aims

There is uncertainty about the usefulness of Broadstrike for the control of broomrape in pastures, particularly those that have high proportions of cretan weed. We do not know whether cretan weed has tolerance to the active ingredient flumetsulam at different stages of development. As a result, the optimal application protocols for Broadstrike remain uncertain. Although there is an incentive for earlier applications of herbicide to allow for optimum growth of pasture species in the absence of weed competitors, this may not meet our goals for broomrape eradication. The aims of this project were:

- to determine the response of cretan weed to flumetsulam (dose response); and
- to determine the optimum application protocol (rate and timing) for Broadstrike application for the control of broomrape on common weed hosts.

The outcomes from this project will enable the eradication program to:

- evaluate the continued use of Broadstrike for branched broomrape control in pastures, particularly pastures with high densities of cretan weed; and
- recommend to landholders the optimum time and rate for the application of Broadstrike for the control of broomrape in pastures.

Methods

Tolerance of cretan weed to flumetsulam

We used a dose response trial to assess the tolerance of cretan weed to the active ingredient in Broadstrike®, flumetsulam. Cretan weed was sown into 0.8 L pots of Burdett sand to which Nitrophoska®

fertiliser had been incorporated. Seeds were sown on 5/10/2010, kept outdoors in an open area on the Waite campus and watered regularly. When sufficient plants had reached the 4-6 leaf stage (about 7 weeks after sowing) herbicide was applied. We applied single doses of Broadstrike at the rates of 0, 10, 15, 20, 25, 30, 40 and 50 g ha^{-1} with the adjuvant Bonza at the rate of 500 ml ha^{-1}. Six replicates were sprayed for each dose using Chris Preston's automated spray facility set at 40 cm above the plants. Extra replicates of the 15, 20 and 25 g ha^{-1} doses were sprayed and another equivalent dose applied to these replicates four weeks later. We applied 0 or 25 g ha^{-1} of Broadstrike to a further six replicates when they had reached the 8-12 leaf stage.

Plants that are tolerant to Group B herbicides are able to metabolise the herbicide before it can be translocated to the growing points where it causes damage. To assess whether cretan weed is metabolising Broadstrike, we applied the metabolism inhibitor, piperonyl butoxide (PBO) to a further set of cretan weed replicates. These plants were at the small rosette or 8-12 leaf stage. PBO was applied at the rate of 2100 g ha^{-1}. The inhibitor was prepared by dissolving it in a 1% solution of ethanol and adding Tween 20 emulsifier. We set up four treatments with six replicates in each:

1) Controls – not sprayed
2) PBO only
3) PBO plus Broadstrike at the rate of 25 g a^{-1}
4) Broadstrike at rate of 25 g ha^{-1}

All plants in these experiments were harvested 28 days after herbicide application. Root and shoot biomass was weighed separately after oven drying at 75 °C for at least 7 days.

Broadstrike timing

This experiment tested the effects of two factors on broomrape occurrence: the timing of Broadstrike application and host type. Turnip weed (*Brassica tournefortii*), cape weed (*Arctotheca calendula*) and cretan weed (*Hedypnois rhagodioloides*) were sown in 200 mm diameter pots filled with Mannum field soil. Pots were filled to two thirds with soil and 1 ml of broomrape seed and 5 ml of Nitrophoska fertiliser was well mixed by hand into the top third of the soil before adding to the pots. After filling, the pots were buried to their rims in the ground at the Mannum trial site set up in five blocks each containing the replicates for all treatments of each species (Fig 1). Host seeds were sown on 7/6/10. Further cretan weeds were sown on 7/6/10 as germination from the early sowing was poor. Host plants were thinned to four turnip plants per pot, one cretan weed per pot and approximately 4-6 cape weeds per pot. Other weeds that appeared in pots were removed.

Broadstrike was applied at the rate of 25 g ha^{-1} at 500, 750, 1000 or 1250 GDD. In a further two treatments we applied two lower rates of Broadstrike (15 and 20 g ha^{-1}) twice, at 500 and 1000 GDD, hereafter called split 1 and split 2 respectively. Controls received no herbicide. We added Bonza adjuvant to herbicide at the rate of 500 ml ha^{-1}. There were five replicates for all treatments.

Plants were harvested after broomrape had emerged and before hosts had died. Host above ground biomass was removed and roots collected. Broomrape plants were removed under a microscope, categorised and counted according to developmental stage. Broomrape biomass and host root biomass was weighed after oven drying at 75 °C for at least 7 days.

Analysis

For the dose response data, data was checked for normal distribution and homogeneity of variances and log-transformed where tests showed there was a significant departure from these assumptions. ANOVA was used to test for differences between treatments. The total biomass data from the 4-6 leaf stage cretan weed was fitted to a dose response curve using the method of Ritz and Streibig (2005). This enables estimation of the effective dose required for a given level of control of the target weed.

Figure 1. Layout of herbicide experiments at Mannum. Broadstrike experiment is in small pots.

For the Broadstrike timing data, we fitted General Linear Models (GLM) to each variable of interest and used *a priori* orthogonal contrasts to test for differences between spray treatments. Models were fitted separately for each host type. We used two sets of contrasts where there was a significant treatment effect. In the first comparison, we compared each treatment separately to the control. In the second comparison, we compared all treatments combined with the control, split applications with single applications, and each GDD timing with other timings. In most cases the data was transformed (log normal +1 transformation) to satisfy model assumptions of normal distribution and homogeneity of variance. Although transformations did not always result in normal distributions, variances were homogeneous for all model fitting. Significance levels for all tests are $\alpha < 0.05$.

For the emergence data in turnip weed there was not sufficient data to fit a GLM so we used a single parameter t-test, testing whether emergence was greater than zero.

Results

Tolerance of cretan weed to flumetsulam

Cretan weed plants that were sprayed with 20 g ha^{-1} or more of Broadstrike declined in growth but there was no significant effect of the herbicide on cretan weed biomass (Fig 2). There was high variability between replicates in most treatments that was not related to spray treatment. Plants observed a few days after spraying showed leaf discolouration and some older leaves died but there was later recovery. No plants were killed in any treatments.

From the dose curve analysis, the ED_{50} (estimated dose for a 50% decline in biomass) was 18.8 g ha^{-1} (Fig 3). ED_{90} was 22.5 g ha^{-1}, less than the current rate of Broadstrike applied (25 g ha^{-1}).

Double doses of Broadstrike applied four weeks apart had no significant effect on cretan weed biomass (Fig 4A). Broadstrike at the rate of 25 g ha^{-1} applied at either the 4-6 leaf stage or the small rosette stage (8-12 leaf) also had no significant effect on cretan weed (Fig 4B).

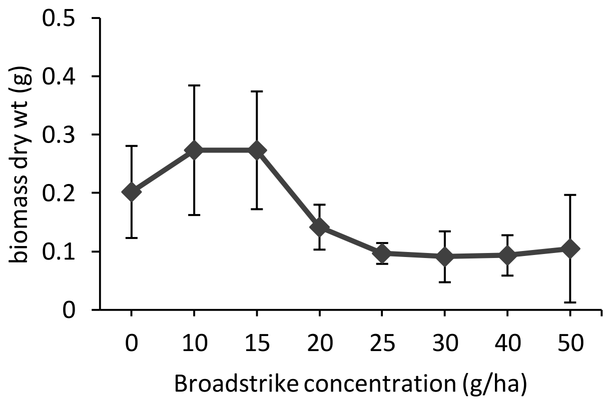

Figure 2. Total biomass of cretan weed plants sprayed at the 4-6 leaf stage with increasing concentrations of Broadstrike. No significant difference between treatments (ANOVA on log-transformed data, *p* = 0.180).

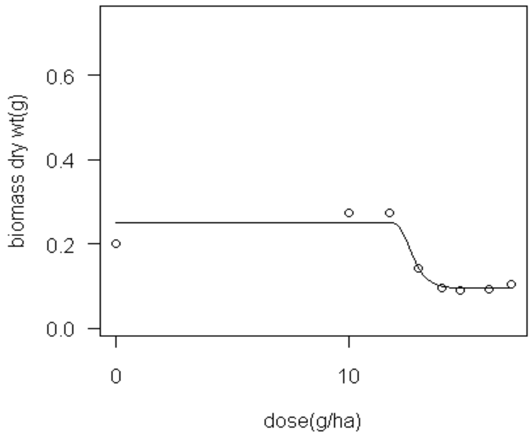

Figure 3. Broadstrike dose response model (Weibull 4 parameter curve) fitted to the cretan weed biomass data as shown in Fig. 2.

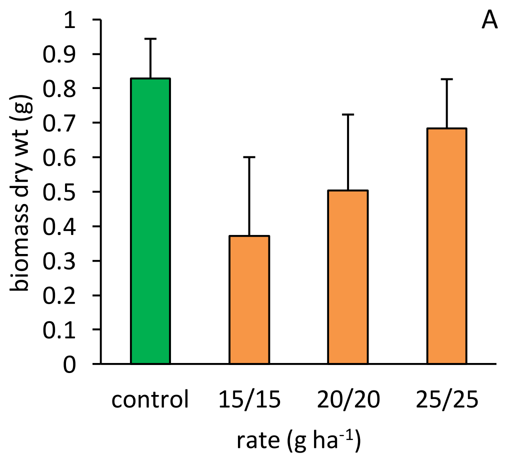

Figure 4. A) Total biomass of cretan weed sprayed with double rates of Broadstrike at the 4-6 leaf stage and again 4 weeks later. There was no significant difference between treatments (ANOVA, *p* = 0.339). B) Total biomass of cretan weed at two stages of maturity sprayed with or without Broadstrike. There was no significant difference between treatments at either stage (ANOVA, *p* = 0.854).

The addition of PBO alone had a significant effect on total biomass so although Broadstrike plus PBO was more effective than Broadstrike alone this was confounded by the effects of PBO (Fig. 5). It was not possible to determine from this data whether metabolism of the herbicide by cretan weed contributes to its tolerance.

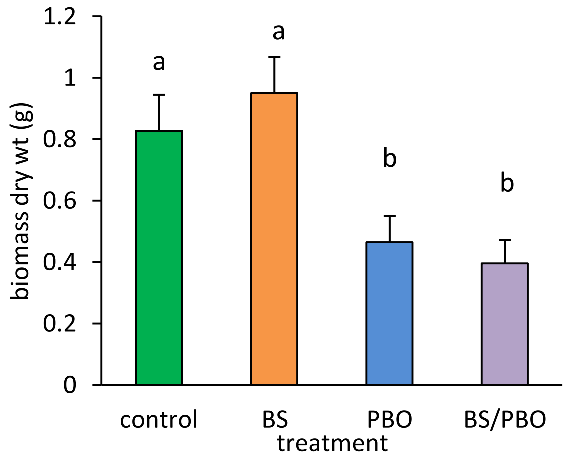

Figure 5. Total biomass of cretan weed plants unsprayed (control), sprayed with Broadstrike at the rate of 25 g ha^{-1} (BS), piperonyl butoxide(PBO) at the rate of 2100 g ha^{-1} or both Broadstrike and PBO. There was a significant difference between treatments (ANOVA, *p* = 0.002). Bars labelled with a different letter were statistically significantly different.

Broadstrike timing

Turnip weed

Turnip weed did not survive when treated with 25 g ha^{-1} Broadstrike at 500 GDD, with single or split applications of less herbicide. Turnip weed sprayed at 750 GDD or later recovered following spraying as shoots killed by the herbicide application later resprouted (Fig 6) but there were persistent effects on root biomass. Plants sprayed at 750 or 1000 GDD had less root biomass than controls (Fig 7).

Broomrape emergence occurred in unsprayed controls but there was no broomrape emergence in any of the sprayed treatments. Broomrape emergence was low on turnip weed controls (1.8 ± 0.58 per pot; mean ± 1SE) but significantly greater than zero (t-test, *p* = 0.037). Dead broomrape tubercles were found on live turnip weed sprayed at 1250 GDD and one dead tubercle occurred on a live turnip weed sprayed at 1000 GDD.

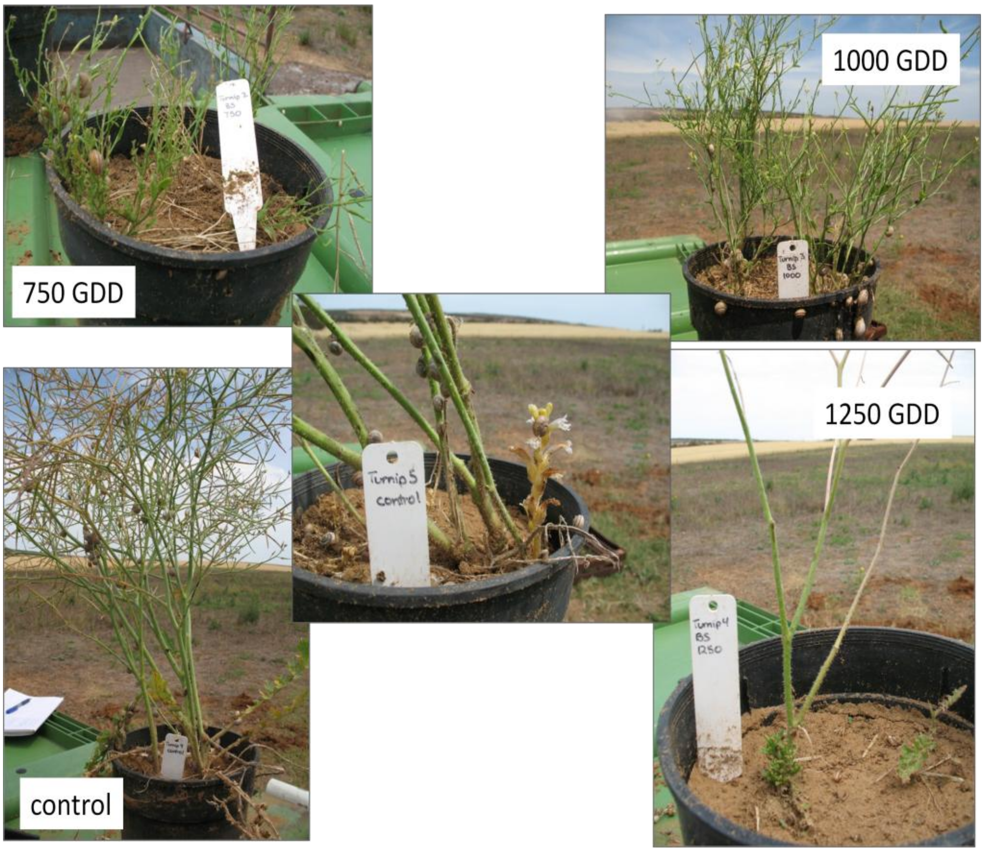

Figure 6. Examples of turnip weed at the time of harvest. Plants have resprouted after spraying. An emerged broomrape plant can be seen on the control. There were no plants surviving in the 500 GDD or split treatments.

Cape weed

Most cape weed was not killed by Broadstrike, with the exception of two plants in the split 1 treatment. Cape weed root biomass was significantly less than controls when sprayed at 500 GDD or where Broadstrike had been applied twice (Fig 7). Visual effects of the herbicide on growth were also observed (Fig 8).

There was very poor infection of cape weed by broomrape. Broomrape emerged on three plants, 2 of these were controls and one was sprayed at 500 GDD. In addition, broomrape tubercles at an advanced stage of underground stem development occurred on cape weed sprayed at 500 GDD. There was no significant difference between the number of live broomrape plants (emerged or advanced) on controls or plants sprayed at 500 GDD ($p = 1$, Fig 9). Live tubercles were also collected from plants sprayed at 1000 GDD but these were not at an advanced stage and would not have been likely to develop to emergence before the death of the hosts. No live broomrape plants were found on the roots of cape weed in other treatments.

Cretan weed

Cretan weed was not killed by Broadstrike and there was no difference in root biomass between treatments ($p = 0.08$; Fig 7). Emergence occurred in all sprayed plots with the exception of those sprayed at 1250 GDD. Pots sprayed at 1000 GDD or sprayed twice with 20 g ha^{-1} at 500 and 1000 GDD had significantly fewer emerged broomrape than controls (Fig 9). In addition, split treatments were more effective than single sprays at 500 – 1000 GDD ($p = 0.03$).

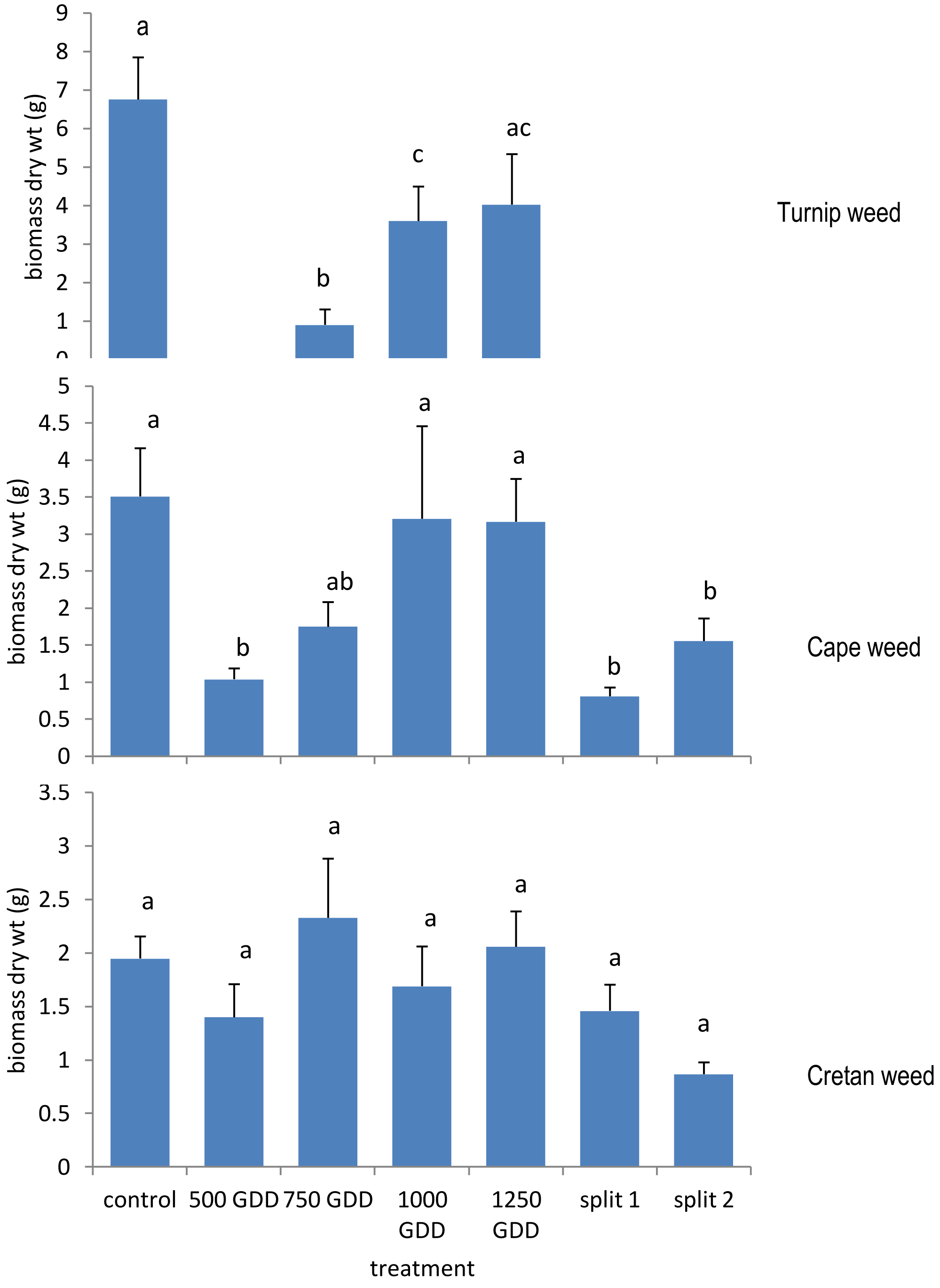

Figure 7. Root biomass of plants sprayed with Broadstrike. Bars labelled with a different letter are statistically significantly different.

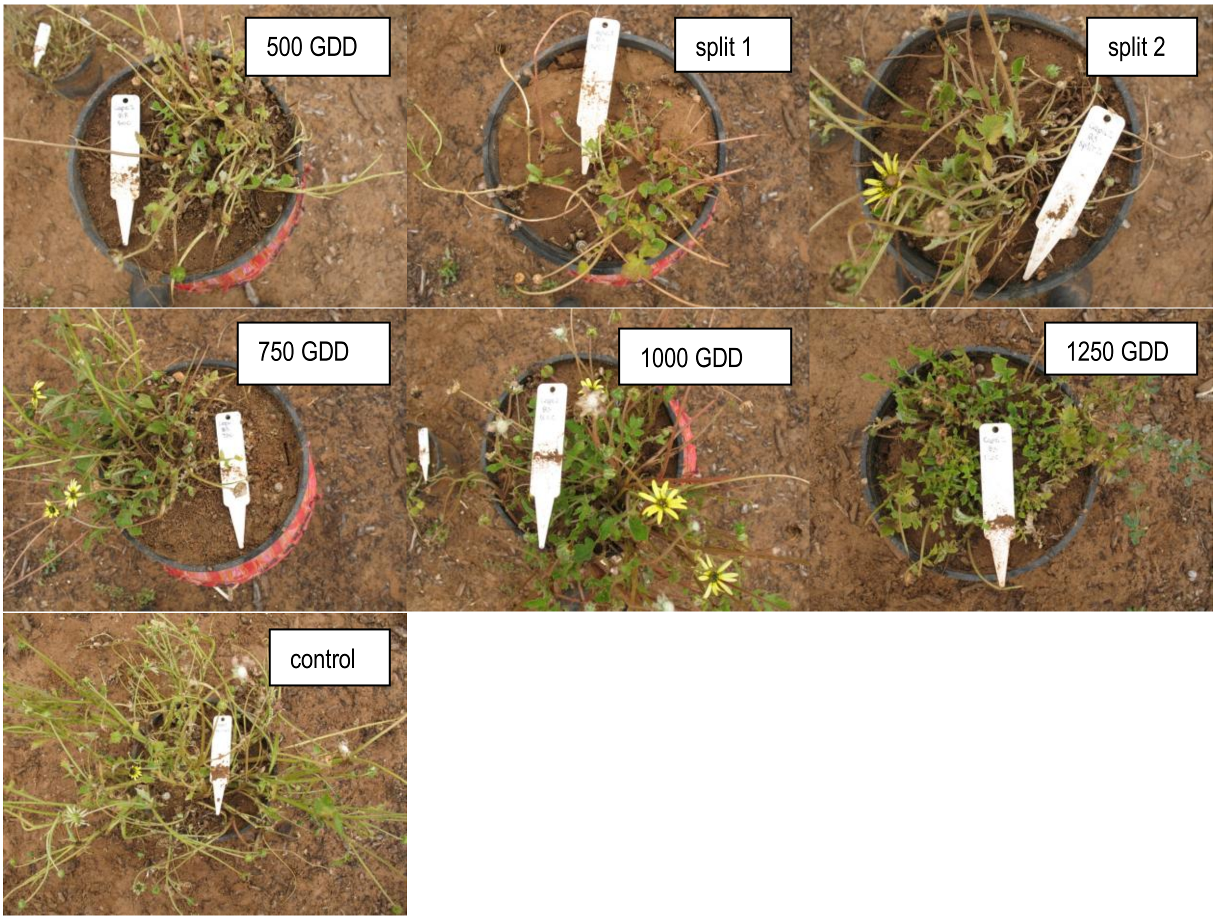

Figure 8. Cape weed plants at time of harvest.

The number of live broomrape tubercles did not differ between treatments (*p* = 0.88). Tubercles at all stages of development were observed on cretan weed roots indicating that infection by broomrape is continuous on this host. The number of new broomrape tubercles (stages prior to development of roots) did not differ between treatments (data not shown, *p* = 0.561). All treatments had tubercles at the stage that could potentially develop to emergence given the survival of the host but there were significant differences in the number of advanced broomrape tubercles between treatments (*p* = 0.021). Controls had significantly more advanced tubercles than sprayed treatments. Plants sprayed at 1250 GDD or sprayed twice at 20 g ha^{-1} at 500 and 1000 GDD had fewer advanced tubercles than other sprayed treatments (Fig 10). The number of dead broomrape tubercles found on roots was very small (overall mean 1.24 or less than 1%) and did not differ between treatments (*p* = 0.826). It is therefore unlikely that Broadstrike was translocated to the host roots and subsequently into broomrape plants. However, shorter-term effects of Broadstrike on cretan weed may have slowed broomrape growth. The biomass of broomrape was affected by spraying (*p* = 0.012). Plants sprayed twice or at 1000 or 1250 GDD had less broomrape biomass than other treatments indicating that broomrape growth is affected by spraying (Fig 11).

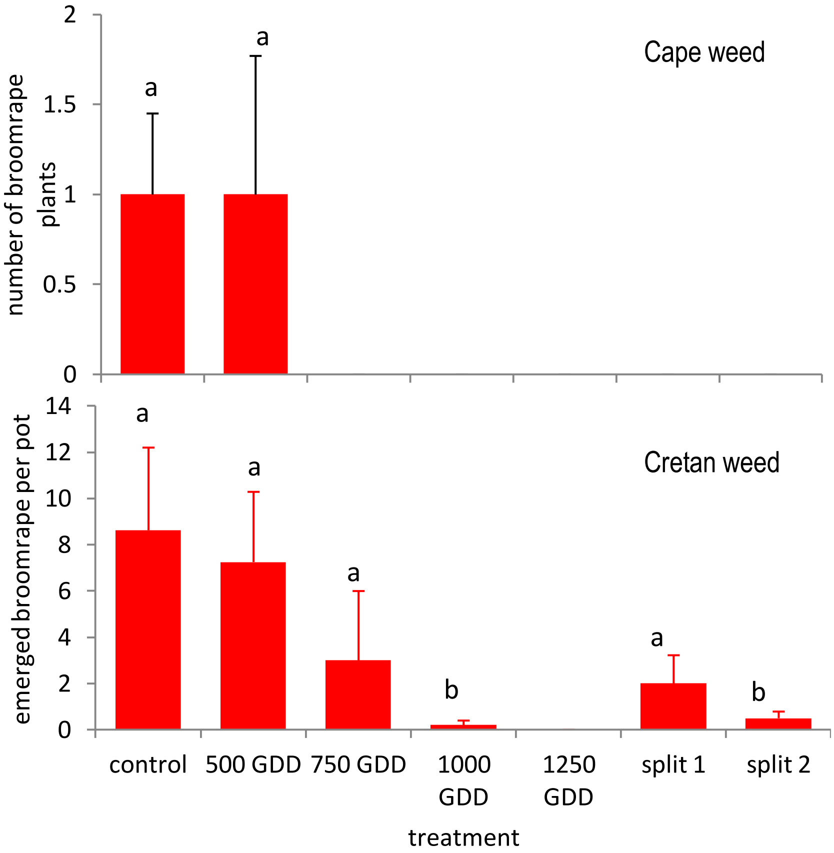

Figure 9. Number of broomrape on cape weed and cretan weed sprayed with Broadstrike at different times (GDD = Growing Degree Days) or with double applications (split). Bars labelled with a different letter are statistically significantly different.

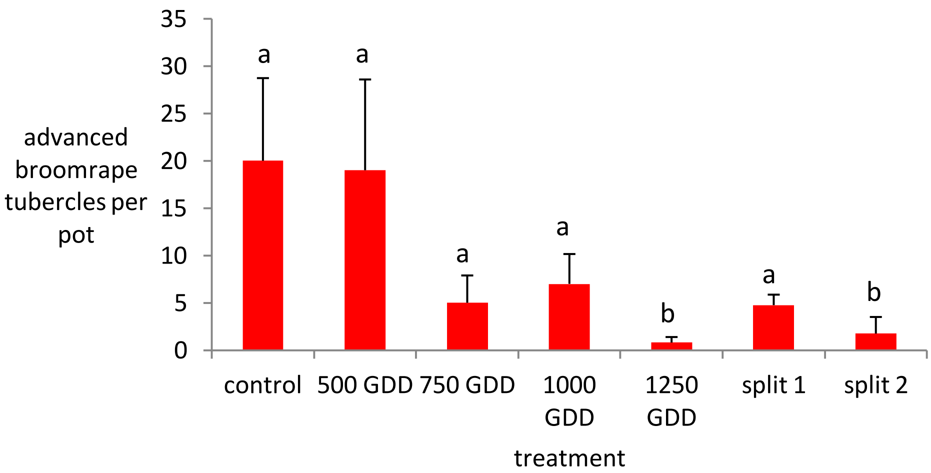

Figure 10. Number of advanced broomrape tubercles on cretan weed sprayed with Broadstrike at different times (GDD = Growing Degree Days) or with double applications (split). Bars labelled with different letters are statistically significantly different from controls.

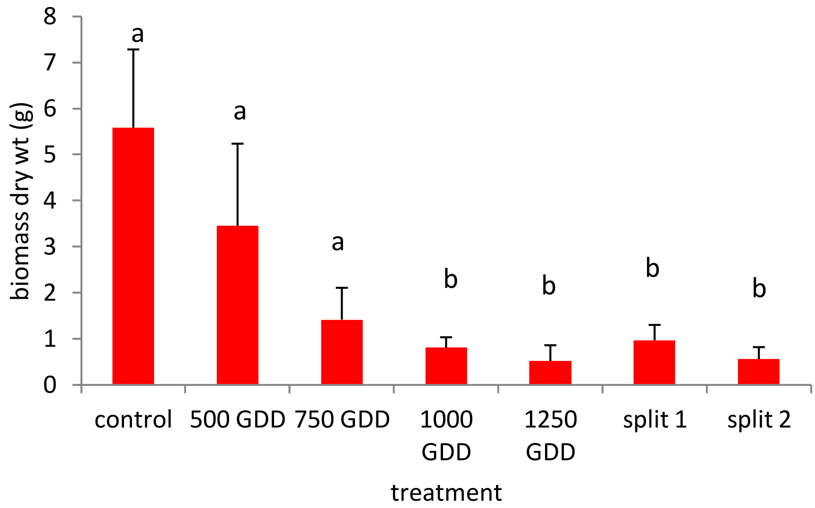

Figure 11. Biomass of broomrape on cretan weed hosts sprayed with Broadstrike at different times (GDD = Growing Degree Days) or with double applications (split). Bars labelled with different letters are statistically significantly different from controls.

Discussion

Broadstrike is not effective for the control of cretan weed. The herbicide had no significant effect on the growth or survival of cretan weed. There were short-term impacts on the growth of individuals but most plants recovered after herbicide application so final biomass of sprayed plants did not differ from controls. Split applications of the herbicide or applications at different stages in cretan weed development are not likely to increase effectiveness. Increasing the current application rate of 25 g ha^{-1} will not improve control of cretan weed.

Although Broadstrike had no effect on cretan weed it did have impacts on broomrape. This is consistent with many of the other ALS inhibitors that are used for broomrape control on hosts that are crops where broomrape control must be achieved with minimal impacts on the host species (Hershenhorn et al 2009, Gressel 2009). There was no evidence that Broadstrike was transferred into broomrape plants from cretan weed hosts as there were very few dead tubercles found and this did not differ between herbicide treatments. Reductions in broomrape were most likely the result of a short-term decline in the transfer of host resources into the parasite in the days immediately following herbicide application. This could be seen in the trend of reduced broomrape biomass on cretan weed with the timing of Broadstrike application (Fig. 11). With earlier sprayings there was time for recovery hence there was no significant difference in broomrape biomass compared to controls with plants sprayed at 500 and 750 GDD. Plants sprayed later had less time for recovery and broomrape biomass was significantly less than controls. Plants sprayed as late as 1250 GDD had insufficient time to develop to emergence. Although late spraying or double sprays with Broadstrike reduced broomrape emergence, none of the spray treatments was completely effective in preventing emergence. Although no plants emerged in the 1250 GDD treatments there were still broomrape plants below-ground at an advanced stage of development that may have emerged given the prolonged survival of the host.

Broadstrike was effective for the control of broomrape on turnip weed by either killing the hosts when sprayed early or killing broomrape attachments on the host plant. It would appear that the herbicide is being translocated to the parasite on this host. For broomrape control, the time of spraying is not crucial although only early sprays at 500 GDD completely killed the host plants.

Broadstrike timing was more important for cape weed hosts. Broadstrike has less impact on this weed although early and double sprays had the most impacts, with root biomass not recovering after spraying. Spraying at 500 GDD did not prevent broomrape emergence therefore later sprayings from at least 750

GDD are necessary. Cape weed plants had very poor broomrape infection so the effectiveness of later timings for broomrape control is tentative.

Cretan weed is a very good host for broomrape. The number of broomrape plants found on this plant was much greater than on turnip weed or cape weed hosts. Broomrape infection occurs throughout the growing season as we found broomrape plants at all stages of development on cretan weed roots. In contrast, only broomrape plants at late stages of development were found on turnip weed and cape weed at the completion of the experiment. Even small populations of cretan weed could provide opportunities for broomrape to persist. The control of this weed is therefore very important to achieve eradication of broomrape.

Recommendations

1. Broadstrike will not prevent broomrape emergence on cretan weed hosts and is not recommended for use in these situations.
2. Broadstrike applied after 750 GDD is the optimal time for controlling broomrape emergence on both turnip weed and cape weed hosts. Where turnip weed only is present then earlier applications will also be effective.
3. The current Broadstrike application rate of 25 g ha-1 is adequate. Increasing this rate will not provide more effective broomrape control on the host weeds tested.
4. Other herbicide options for cretan weed must be investigated due to the excellent host potential of this weed for broomrape.

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14. Cretan weed herbicide efficacy trial

Tom McInerny

Rural Solutions

2005

From Agronomy Matters

Cretan weed is an important weed in regard to broomrape as it is one of the most favoured hosts of broomrape. Chemical control of cretan weed is also quite difficult in a pasture situation as the products which are soft on medics (e.g. Broadstrike) have little effect on cretan weed. As can be seen from Table 1, any spray treatment that did a good job in controlling cretan weed also did a lot of damage to the stand of medic. Products that performed best were those products containing the bromoxynil, diflufenican and MCPA ester.

Trials in 2006 will aim to test more promising chemicals and also to manipulate some of the rates to achieve good cretan weed control while still maintaining a healthy stand of medic.

Table 1. Results for cretan weed herbicide efficacy trial. Cretan weed is a major host of branched broomrape and in the same family as capeweed and native daisies.

Product	Rate per ha	Cretan weed % reduction in biomass	Cretan weed % dead	Medic % reduction in biomass	Capeweed % reduction in flowers
Jaguar	1 L	100	100	72	100
Bromicide 200	2 L	99	99	70	100
Bromoxynil M	1.4 L	97	97	73	100
Tigrex	1 L	87	85	67	85
Starane	1 L	73	75	95	53
Lontrel + MCPA	100 ml + 1 L	72	13	97	100
LV Estercide (high)	900 ml	53	15	96	80
Banvel M	1 L	37	8	93	92
MCPA LVE	1.7 L	35	0	93	70
MCPA Amine	2.1 L	30	0	85	75
Amicide 625	1.7 L	30	0	87	75
Raptor	45 g	28	0	37	100
LV Estercide (low)	600 ml	27	0	88	78
Midas	900 ml	23	0	92	100
Lontrel (high)	300 ml	22	0	99	100
Agtryne MA	1 L	3	3	23	92
Lontrel (low)	100 ml	3	0	82	100
Banvel 200	550 ml	2	0	93	90
Broadstrike	25 g	0	0	0	100
Diuron	500 g	0	0	3	53

15. Cretan weed herbicide trial 2009

Keith Bolto and Tanja Morgan

Rural Solutions

From Agronomy Matters

Key Messages

- All treatments caused a reduction in medic biomass
- Broadstrike + Jaguar or Jaguar on its own gave the best results on cretan weed, however also reduced medic biomass by about 50%.
- Controlling broomrape in medic and cretan weed pastures will be a compromise between broomrape control and acceptable damage.
- Consider grazed cereals as an alternative to medic pastures that have cretan weed.

Cretan weed remains a major issue for landholders trying to control broomrape in pastures. The problem is that herbicides that successfully control cretan weed also have a significant impact on medics and other broadleaf weed species commonly found in regenerating pastures. This affects the amount of available feed in a pasture and contributes to declining medic population.

Broadstrike has been used in pastures with cretan weed with variable results but greater medic safety and remains the most useful product we have at this point in time. Therefore the aim of this trial was to mix Broadstrike with low rates of different broadleaf weed herbicides to try and get a better result on reducing cretan weed without causing too much medic damage.

The trial was conducted in a self-regenerating pasture paddock at Mannum. All the usual weed suspects were present, including cretan weed, capeweed, turnips, tolpis and skeleton weed. Medic density was excellent at around 50%.

Herbicide was applied on the 5th June (650 GDD) to cretan weed 5 – 15 cm in diameter. This is considered to be an early timing for Broadstrike to achieve better control on small weeds. The majority of farmers under Farm Plan are applying Broadstrike at 1000-1300 GDD for the purpose of removing broomrape attachments only.

Visual scores were collected 13 days after treatment (DAT) and 40 DAT.

Results

The results show that there are no treatments that effectively kill cretan weed without causing a reduction in medic biomass (Table 1). When assessing treatments, it's important to compare both sets of scores as some plants (cretan weed and medic) recovered over time and some reduced further in biomass.

Medic was affected by spraying Broadstrike alone in 3 of the four treatments, although this result is not always evident in a paddock situation. There are a number of reasons why this may have happened:

- There are two distinct types of medic at the trial site (yet to be identified) and one variety appeared to be more sensitive to the herbicides applied.
- Plants may have been suffering cold, nutrient or moisture stress which can affect their ability to tolerate herbicide.
- Broadstrike can cause a slight decrease in biomass, but plants generally always recover as the season progresses.

Table 1. Products used in trial and effects on cretan weed and medic biomass.

Product	Rate/ha	Adjuvant	Cretan weed % reduction in biomass 13 DAT	Medic % reduction in biomass 13 DAT	Cretan weed % reduction in biomass 40 DAT	Medic % reduction in biomass 40 DAT
Control	Nil	Nil	0	0	0	0
Broadstrike	25 g	Uptake 500 ml / 100 L	4	14	7	19
Broadstrike + Diuron	25 g + 200 ml	BS 1000 100 ml/ 100 L	14	22	9	20
Broadstrike + Bromoxynil 200	25 g + 700 ml	Uptake 500 ml / 100 L	45	32	32	32
Broadstrike + Buttress	25 g + 2.5 L	Uptake 500 ml / 100 L	56	20	56	35
Broadstrike + Jaguar	25 g + 500 ml	Uptake 500 ml / 100 L	100	60	100	55
Broadstrike + Brodal	25 g + 100 ml	Uptake 500 ml / 100 L	61	25	67	32
Broadstrike + Igran	25 g + 300 ml	Uptake 500 ml / 100 L	52	41	37	41
Broadstrike + Ally	25 g + 1 g	BS 1000 100 ml/ 100 L	26	34	36	63
Jaguar	500 ml	None	75	65	62	56

This would also support the feedback we receive from farmers with many getting on really well with Broadstrike, but others seeing negative effects in their medic pastures. Removing weeds from pastures may also give the impression that medic biomass has been affected as these areas become bare of weeds.

In the 2005 cretan weed trial (see Section 10.9), Broadstrike caused no reduction in medic biomass. Treatments were visually scored late October demonstrating that any reduction in biomass as a result of Broadstrike was no longer visible later in the season. Less weed competition from early control also helps medic plants respond to more available moisture and nutrients.

Good results with cretan weed control were achieved with Bromoxynil 200, Jaguar and Brodal when mixed with Broadstrike. These products contain the active ingredients bromoxynil and/or diflufenican. Unfortunately medic biomass was reduced considerably, however it may be worth revisiting a mix of Broadstrike + Jaguar at a lower rate (e.g. 250 ml/ha) to see if cretan weed control can still be achieved with less damage to medics.

This trial clearly demonstrates the difficulty in controlling weeds and broomrape in pasture paddocks. Alternatives to self-regenerating pastures, such as grazed cereals or grain crops are recommended where problem weeds such as cretan weed exist.

If grazed cereals or crops are not an option then spraying pastures with Broadstrike alone or in a mix with some of the trialled products is still necessary. Consider the reduction in medic biomass you are willing to accept to gain better control of weeds and prevent broomrape emergence. Alternatively, glyphosate (450 g/L) can be applied at 0.6 – 1.2 L/ha between 1000-1300 GDD if season permits.

16. Herbicides for branched broomrape control in medic pastures

Jane Prider, Andrew Craig

Branched Broomrape Eradication Program

December 2010

Summary

The current herbicide options for control of branched broomrape in pastures are not adequate for the control of cretan weed. In this pot experiment we examined the effects of three herbicides on cretan weed, broomrape and Angel medic. Express, *a.i.* tribenuron methyl, an ALS inhibitor, prevented broomrape emergence on cape weed and cretan weed at rates of 20 g ha^{-1}. However, most medic plants were killed at this rate. Two other herbicides, Brodal and Bromoxynil, were applied in combination with Broadstrike (25 g ha^{-1}). Broadstrike with Brodal, at the rate of 80 ml ha^{-1}, had severe effects on cretan weed when sprayed late at 1000 GDD but not when sprayed earlier. This herbicide reduced but did not prevent broomrape emergence. Broadstrike with Bromoxynil, at the rate of 600 ml ha^{-1}, resulted in compete mortality of cretan weed when sprayed at 500 GDD and almost killed cretan weed when sprayed at 1000 GDD. There was no broomrape emergence from plants sprayed with the Bromoxynil/ Broadstrike mixture. Medic plants survived applications of Brodal and Bromoxynil with Broadstrike and developed at least until the flowering stage when the experiment terminated. Bromoxynil/Broadstrike had some impacts on medic growth as plants sprayed at 1000 GDD had less biomass than plants sprayed at 500 GDD.

Bromoxynil plus Broadstrike was the most effective herbicide for broomrape control on cretan weed out of the three herbicides tested. The effects of this herbicide on medic require further quantification. The application protocol for this herbicide requires further refining, although 600 ml ha^{-1} applied at 500 or 1000 GDD effectively prevented broomrape emergence in this trial.

Introduction

There is a need to continue to test herbicides for branched broomrape control. Although there are adequate choices of herbicides for use in crops, there is still a need for an effective herbicide for control of branched broomrape in medic and volunteer pastures. Cretan weed hosts have proven to be intractable in pasture situations and an effective herbicide is still required for this weed.

The systemic Group B herbicides or acetolactase synthase (ALS) inhibitors have been found to be the most effective for the control of broomrape. These herbicides have the advantage that they are selective and can be active against broomrape at very low rates without severely impacting the host plant or non-target species. Tribenuron methyl is in the sulfonylurea group of ALS inhibiting herbicides. John Matthews has trialled this herbicide for long season control of broomrape (presume not successful) but its effectiveness in the short-term has not been tested. It has been found to have limited success for control of broomrape in other situations (Dhanapal et al 1998, Hershenhorn et al 1998). The effect of this herbicide on medics is not known.

Although Broadstrike is the preferred Group B herbicide for use in pastures due to the tolerance of some pasture species, particularly medics, it is not very effective on broomrape infecting cretan weed. Trials by Rural Solutions of herbicide mixtures with Broadstrike, identified Brodal (*a.i.* diflufenican) and Bromoxynil as having the most impact on cretan weed and the least impact on medic (Bolto & Morgan 2009).

Broadstrike was applied at a rate of 25 g ha^{-1} in mixtures with Bromoxynil at 700 ml ha^{-1} or Brodal at 100 ml ha^{-1}. These rates produced some damage to medic and it is not known if these rates would be effective for broomrape control. It is also possible that lower rates of Brodal and Bromoxynil may suppress cretan weed and also achieve broomrape control whilst lessening medic damage.

The following questions will be addressed in this project:

5. Are applications of tribenuron methyl effective for controlling branched broomrape on common weedy hosts?
6. Do low rates of Brodal or Bromoxynil in combination with Broadstrike provide control of branched broomrape on cretan weed hosts?

The outcomes from this project will enable the eradication program to potentially provide additional choices for herbicides that can be used in medic pastures for broomrape control.

Methods

We tested the herbicides on two host mixtures: cape weed (*Arctotheca calendula*) or cretan weed (*Hedypnois rhagadioloides*) grown with Angel medic (*Medicago littoralis*). Host mixtures were grown in 8 L pots (250 mm diameter) filled with Mannum field soil. Pots were filled to two thirds with soil and 2.5 ml of broomrape seed and 30 ml of Osmocote® fertiliser was well mixed by hand into the top third of the soil before adding to the pots. After filling, the pots were buried to their rims in the ground at the Mannum trial site. Host seeds were sown on 7 June 2010. The cretan weed mixtures were set up in five blocks each containing the replicates for all treatments of each species. The cape weed mixtures formed a single block (Fig 1). Plants were regularly watered throughout the experiment.

Figure 1. Layout of herbicide experiments at Mannum. This experiment is in the larger pots.

Express herbicide was applied at 1000 GDD at the rates of 10, 20 and 30 g ha^{-1} to the cape weed and cretan weed mixtures. Brodal/ Broadstrike (BS) and Bromoxynil/BS treatments were applied to the cretan weed plus medic hosts only. Bromoxynil was applied at a rate of 600 ml ha^{-1} and Brodal at a rate of 80 ml ha^{-1} in mixture with Broadstrike (25 g ha^{-1}) plus Bonza adjuvant (500 ml ha^{-1}) at 500 or 1000 GDD. Due to the lack of emergence of cretan weed in some pots, the Express 10 g ha^{-1} treatment was omitted for cretan weed and not all treatments had the planned five replicates (Table 1).

Plants were harvested after broomrape had emerged and before hosts not killed by herbicide had died. Host above ground biomass was removed and medic shoot biomass was collected and soil rinsed from roots. Broomrape plants were collected from cape weed hosts when roots were washed out. Roots from cretan weed pots were collected and broomrape plants were removed under a microscope, categorised and counted according to developmental stage. Broomrape biomass, medic shoot biomass and host root biomass from cretan weed pots was weighed after oven drying at 75 °C for at least 7 days.

Table 1. The number of replicates for each of the herbicide treatments

Herbicide treatment	Cretan weed + medic	Cape weed + medic
Control	4	5
Express 10 g ha^{-1}	2 (medic only)	5
Express 20 g ha^{-1}	3	5
Express 30 g ha^{-1}	5 (1 medic only)	5
Brodal + Broadstrike 500 GDD	5	0
Brodal + Broadstrike 1000 GDD	4	0
Bromoxynil + Broadstrike 500 GDD	5	0
Bromoxynil + Broadstrike 1000 GDD	2	0

Analysis

We fitted General Linear Models (GLM) to each variable of interest and used *a priori* orthogonal contrasts to test for differences between spray treatments. Models were fitted separately for each host type. In most cases where a treatment had all zero values for the variable of interest, these zero data were removed. For contrasts, we compared all treatments combined with the control, and compared between treatment levels for each herbicide, ignoring controls. In most cases the data was transformed (log normal +1 or square root transformation) to satisfy model assumptions of normal distribution and homogeneity of variance.

Results

Express herbicide

Express herbicide had different impacts on the three target plants, cape weed, cretan weed and Angel medic. Cape weed was not killed by applications of Express at any of the application rates. Cretan weed was killed by applications of 20 g ha^{-1} but not all cretan weed was killed by applications of 30 g ha^{-1}. Angel medic survived applications of 10 g ha^{-1} but was either killed or leafless at higher rates. Images of sprayed cretan weed are in Appendix A.

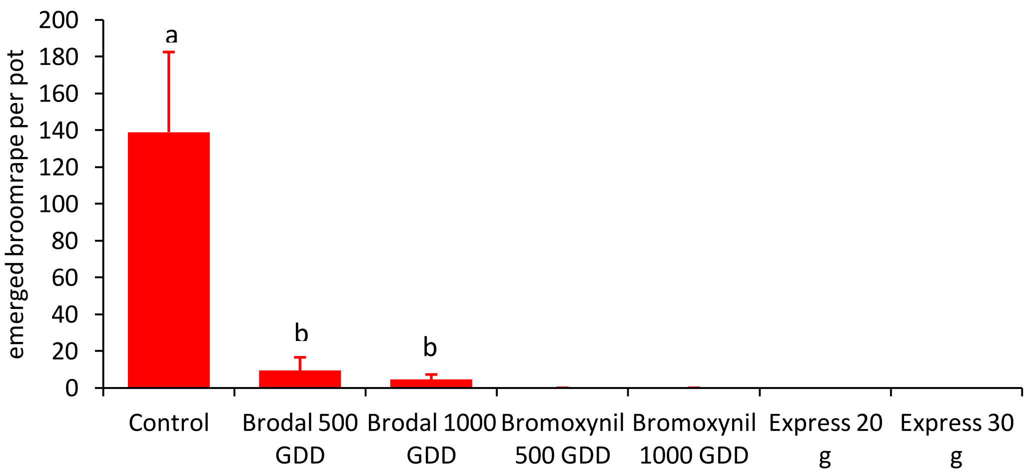

Figure 2. Numbers of emerged broomrape plants from pots planted with cretan weed and medic. Bars (mean ± 1SE) labelled with different letters are significantly different.

No broomrape plants emerged from cretan weed + medic sprayed with Express although the unsprayed control treatment had large numbers of emerged plants (Fig 2). Broomrape infection of cape weed was poor and only one control plant survived, although all sprayed plants survived. There was broomrape emergence on cape weed sprayed with Express at 10 g ha^{-1} (1.2 ± 0.49; mean ± 1SE) but not at higher application rates.

Cretan weed sprayed with Express 30 g ha^{-1} had fewer broomrape tubercles than controls but not plants sprayed with Express 20 g ha^{-1} (Fig.3). Most of the tubercles on sprayed plants were dead and live broomrape was found only on the surviving medic plants in the 20 g ha^{-1} treatment. There were small live tubercles on the surviving cretan weed in the 30 g ha^{-1} treatment but they were not likely to develop to emergence (no underground stems had developed).

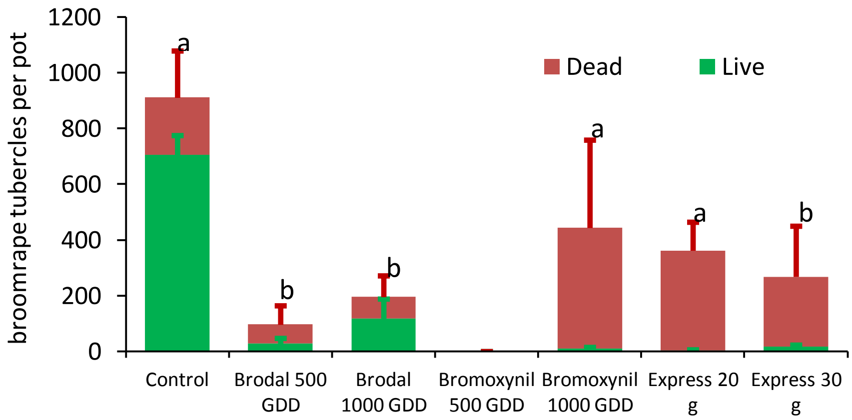

Figure 3. Number of live and dead broomrape tubercles (un-emerged plants) in pots planted with cretan weed and medic. Bars (mean ± 1SE) labelled with different letters are statistically different to controls (Dead + live broomrape).

Brodal or Bromoxynil with Broadstrike (BS)

Of the two herbicides used in mixture with Broadstrike, Bromoxynil had greater effects on cretan weed survival than Brodal. Brodal/BS was more effective on cretan weed when sprayed at 1000 GDD than at 500 GDD. Images taken of plants when harvested show that some plants were almost killed when sprayed at the later date (Appendix A). Conversely, Bromoxynil/BS completely killed cretan weed when sprayed at 500 GDD and plants were almost killed when sprayed at 1000 GDD (but there were few replicates in the 1000 GDD treatment, see Appendix A).

Where Angel medic was present, plants were in leaf and flowered when sprayed by either of the herbicide mixtures at both spray times (Appendix A). The later sprayings of Brodal and Bromoxynil resulted in a greater reduction in medic shoot biomass than the early sprayings (Fig. 4). There were no medic plants in controls so it is not possible to determine whether shoot biomass was reduced by spraying at 500 GDD.

There was no broomrape emergence from pots sprayed with Bromoxynil/BS. There was broomrape emergence from pots sprayed with Brodal/BS but this was significantly less than controls. There was no difference in the timing of Brodal/BS application on emergence (Fig. 2).

Pots sprayed with Brodal/BS had significantly fewer broomrape tubercles (non-emerged) than controls but the number of dead tubercles did not differ between controls and Brodal/BS-sprayed plants. The number of broomrape tubercles on plants sprayed with Bromoxynil/BS at 1000 GDD did not differ from controls but the majority of the tubercles on sprayed plants were dead (Fig. 3). The live tubercles in these pots were found on medic hosts. No broomrape was found in the Bromoxynil/BS 500 GDD treatments.

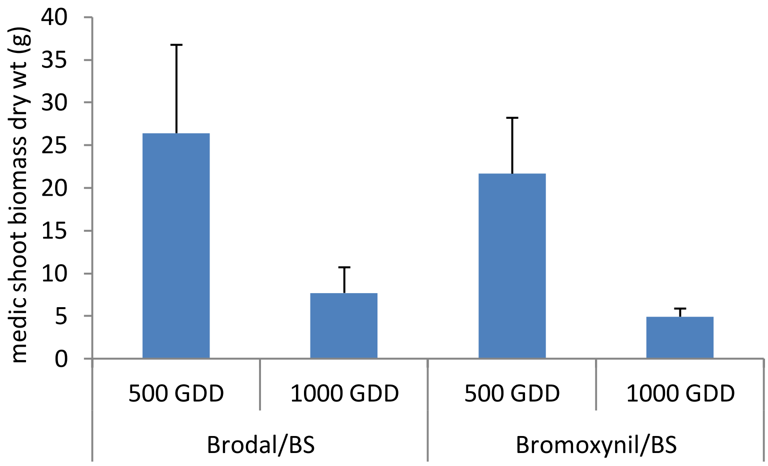

Figure 4. Shoot biomass of Angel medic plants sprayed with Brodal or Bromoxynil plus Broadstrike at two spray times (mean ± 1SE, *n* = 2 for each treatment).

Discussion

The three herbicides used in these trials had impacts on cretan weed. Bromoxynil/BS was consistently more effective than Brodal/BS and Express. There may have been problems with the penetration of Express herbicide as the 20 g ha^{-1} treatments did more damage to cretan weed than the 30 g ha^{-1} application. An adjuvant was not used with this herbicide and may improve performance. Express had no visually discernible effects on cape weed, which reduces the usefulness of Express herbicide for multiple weeds. For Bromoxynil/BS, the 500 GDD treatment was possibly more effective than the 1000 GDD timing but low numbers of cretan weed surviving to the later spray time reduced the number of replicates and hence the reliability of this result. The late Brodal/BS spray timing was more effective than early spray timing.

Express resulted in considerable damage to Angel medic and only applications of up to 10 g ha^{-1} could be considered for use in medic pasture. There were no visual effects of Brodal/BS or Bromoxynil/BS on Angel medic plants sprayed at 500 or 1000 GDD. Medic biomass was reduced in the later spraying so an early spray time would be preferable to reduce medic impacts. Due to the poor emergence of Angel medic in our trails, these results are only based on a limited number of plants. Further quantification of the effects of the herbicide mixtures on medic are required. Bromoxynil applied at the label recommended rate of 1000 ml ha^{-1} was found to have severe effects on annual medics, including *M. littoralis* (Young *et al.* 1992). Although the rate used here was less (600 ml ha^{-1}), the effects on medic growth, reproduction and yield may be reduced further with lower rates whilst still achieving cretan weed and broomrape control.

Applications of Express and Bromoxynil/BS completely prevented broomrape emergence on cretan weed hosts. For Bromoxynil/BS, this was probably a result of host survival, the host being killed or almost killed by the herbicide application. As cretan weed was not killed by Express then the herbicide was possibly translocated to the broomrape plants and resulted in their death. Bromoxynil sprayed at emergence of *O. minor* in red clover did not reduce the density of the weed, indicating the herbicide may not have direct impacts on Orobanche (Lins et al. 2005).

Brodal/BS appears to have different impacts on broomrape. Hosts were not killed by this herbicide combination. Our other work has shown that Broadstrike does not kill attached broomrape on cretan weed hosts. Diflufenican, the active ingredient of Brodal, has only limited foliar translocation so there may have been little transport to the roots. Brodal is a Group F herbicide or carotenoid biosynthesis inhibitor and disrupts photosynthesis so is not likely to directly impact broomrape. As carotenoids are the precursors of strigolactones, the herbicide could reduce strigolactone release and hence broomrape germination. This may explain the fewer broomrape attachments on Brodal-treated plants than controls. Other carotenoid inhibitors were found to reduce *Striga* infection when applied to rice (Jamil *et al* 2010). Reductions in the transport of the products of photosynthesis (carbon) into roots could also explain the low infection of broomrape on cretan weed sprayed with Brodal.

Recommendations

1. Express herbicide is effective at preventing broomrape emergence on cretan and cape weed at rates of 20 g ha-1 but has unacceptable negative effects on medic at this rate. This herbicide is not registered for use in South Australia. For these reasons, this herbicide is not recommended for broomrape control in pastures at this stage.
2. Bromoxynil in mixture with Broadstrike is more effective for broomrape control than Brodal. Bromoxynil should be considered further for broomrape control where cretan weed is present. The rates trialled here (600 ml ha-1 with 25 g ha-1 of Broadstrike) were effective when applied at 500 GDD. Applications at 1000 GDD were also effective although low replication for this treatment reduces the reliability of these results.
3. Bromoxynil/BS had no visual impacts on Angel medic although the effects of the herbicide on medic, including other varieties, need to be quantified. Later applications may reduce biomass and yield. More trial work is therefore required.
4. Application rates and timing for Bromoxynil could be further refined to provide optimal control for cretan weed and medic whilst minimising medic impacts. Doses that are sublethal to cretan weed may not provide effective broomrape control and this needs to be investigated. Further trials are also required to determine whether cretan weed control can be achieved under different environmental conditions.

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17. Jaguar trial for medic pastures with cretan weed

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January 2011

Aim

The aim of this trial was to determine the rate of Jaguar that could be applied to a medic paddock with cretan weed that would maximise cretan weed control whilst minimising medic damage.

Methods

Experiment design

The trial was conducted by Steve Lamey and Rural Solutions in a voluntary pasture paddock with medic and cretan weed. The herbicide Jaguar was applied to 70 m strips at different rates on 21/8/2010 (987 GDD according to nearest weather station data). Jaguar was applied in mixture with Broadstrike (25 g ha^{-1}) at rates of 0, 200, 300, 350, 400, 500 ml ha^{-1}. There was also a treatment of Broadstrike only.

Within four 10 m strips in each sprayed area, 20 small cretan weed plants (< 40 mm diameter) were marked so that they could be later monitored. The condition of these plants was scored visually 27 days after spray application. Scores ranged from 0 (dead) – 5 (no visible damage). The condition of medic was informally assessed in four 30 cm by 30 cm subplots within each sprayed strip. Similar scores were assigned as for cretan weed. These plots were photographed and the images were used to confirm the informal visual condition scores for medic plants.

Later assessment of condition could not be made as the strips were unexpectedly sprayed out by the owner in early October.

Analysis method

We calculated the average cretan weed condition score and proportion of surviving plants for each replicate plot. For medic condition, we completed the condition scores from the plot photographs. The data for analysis comprised four values (or replicates) for each treatment.

We tried to apply a standard analysis to these data, testing for significant differences between treatments but the distribution of the data and the variances could not be satisfactorily transformed to conduct any of these tests (*e.g.* ANOVA). For this type of analysis the data must fit (or almost fit) a straight line but the data set is distinctly non-linear (see the plot below).

Instead we fitted separate dose response curves for the condition score for cretan weed and medic and the proportion cretan weed surviving. The doses are the values on the x axis and the y values are the condition scores or proportion survival scores for each replicate (the plot shows the means of these values for each dose). This type of analysis fits a non-linear curve to the data. It is a matter of finding the equation of the curve that fits the data the best. There was not any significant difference between the fits of three parameter or four parameter logistic models and the parameters of both models provided a significant fit to the data according to ANOVA tests. As the four parameter model flattens out at larger doses and the data was still showing a decreasing trend at the largest doses, the three parameter model was selected as the more appropriate. The models were used to calculate estimated doses, or the doses required for a given response as a proportion of the control score. Standard estimated doses (ED) are reductions in control condition of 10, 50 and 90%.

Results

Cretan weed condition score

A three parameter logistic curve was fitted to the cretan weed condition scores (Figure 1). For the zero dose, the controls and Broadstrike alone treatments have been combined. Table 1 shows that the parameters for the curve (intercepts) provide a significant fit to the data.

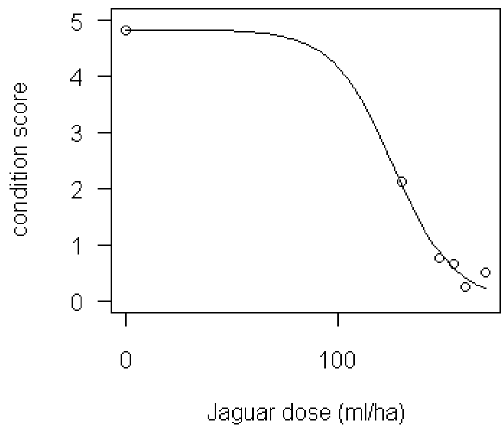

Figure 1. Jaguar dose response curve for cretan weed condition

Table 1. Parameter estimates for Model fitted to cretan weed condition data: 3 Parameter Log-logistic

	Estimate	Std. Error	t-value	p-value
b:(Intercept)	3.024713	0.362358	8.347306	1.073e-08
d:(Intercept)	4.833329	0.099848	48.406731	1.562e-26
e:(Intercept)	182.748049	8.787061	20.797402	1.342e-17

Residual standard error:
0.2826075 (25 degrees of freedom)

An estimated dose of 378 ± 23 ml/ha would reduce the condition score by 90% (Table 2). The model predicts that doses less than those applied in this trial (200 ml) would also have an effect on cretan weed condition.

Table 2. Estimated effective doses of Jaguar for cretan weed condition

	Estimate	Std. Error
ED10	88.383	11.2328
ED50	182.748	8.7871
ED90	377.863	22.7291

Cretan weed survival

A three parameter logistic curve was fitted to the cretan weed survival scores (Figure 2). As 100% mortality has not been achieved at the doses applied, the curve does not flatten out at the highest doses. The curve provides a significant fit to the data (Table 3).

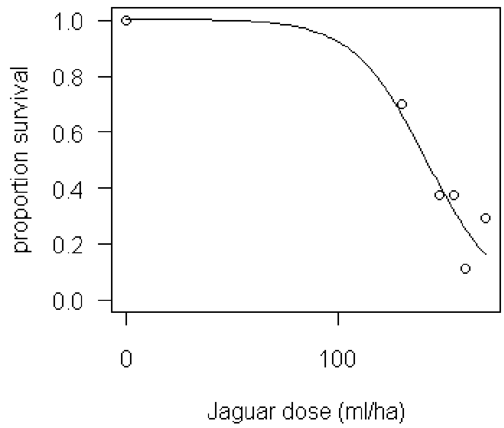

Figure 2. Jaguar dose response curve for cretan weed survival

Table 3. Parameter estimates for Model fitted to cretan weed survival data: 3 Parameter Log-logistic

	Estimate	Std. Error	t-value	p-value
b:(Intercept)	2.537809	0.546458	4.644105	1e-04
d:(Intercept)	1.003724	0.046974	21.367694	7.067e-18
e:(Intercept)	260.854066	19.985033	13.052471	1.160e-12

Residual standard error:
0.1340042 (25 degrees of freedom)

According to the model, a Jaguar dose of 620 ± 100 ml/ha is required to achieve 90% kill of cretan weed (Table 4). A dose of 260 ± 20 ml/ha will kill approximately half of the plants.

Table 4. Estimated effective doses of Jaguar for cretan weed survival

	Estimate	Std. Error
ED10	109.75	25.741
ED50	260.85	19.985
ED90	620.02	100.431

Medic condition

A three parameter logistic curve was fitted to the medic condition scores (Figure 3). I omitted the control values and used the Broadstrike alone values as the zero Jaguar dose as Broadstrike alone had some impact on medic condition scores. This curve provided a significant fit to the data with the exception of the parameter for the slope (Table 5).

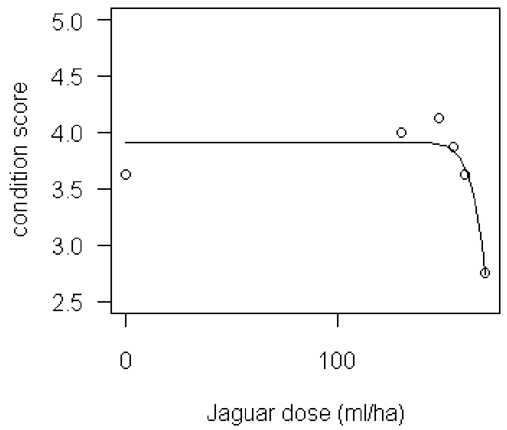

Figure 3. Jaguar dose response curve for medic condition

Table 5. Parameter estimates for Model fitted to medic condition data: 3 Parameter Log-logistic

	Estimate	Std. Error	t-value	p-value
b:(Intercept)	8.74977	5.68377	1.53943	0.1386
d:(Intercept)	3.91492	0.16437	23.81769	5.552e-17
e:(Intercept)	550.90590	41.86037	13.16056	1.303e-11

Residual standard error:
0.5813555 (21 degrees of freedom)

Broadstrike alone had a significant impact on medic condition (heteroscedastic t-test, $p = 0.01$). The mean condition score for sprayed plants was 3.6 whilst unsprayed plants had a score of 5. The dose analysis shows that increasing Jaguar rates whilst maintaining the same Broadstrike rate does not have an increasing negative effect on medic condition. Jaguar rates up to about 400 ml ha^{-1} have only a small impact on medic: 10% reduction in condition (ignoring the effects of Broadstrike). Doses over 500 ml ha^{-1} result in a 50% reduction in medic condition score, which would be unacceptable together with the effects of Broadstrike (Table 6).

Table 6. Estimated effective doses of Jaguar for medic condition

	Estimate	Std. Error
ED10	428.57	47.07
ED50	550.91	41.86
ED90	708.17	162.58

Discussion

Our model predicts that a Jaguar rate (+Broadstrike) of 350 ml ha^{-1} would result in a 90% reduction in cretan weed whilst having the least effect on medic. What is not known is whether broomrape would be adequately controlled without completely killing cretan weed. The analysis predicts that a dose of 680 ml ha^{-1} of Jaguar (+Broadstrike) would be required to completely kill cretan weed but this would result in a greater than 50% reduction in medic condition which is unacceptable. However, it is not known whether there were further changes in the results (recovery or further decline) as the trial was prematurely terminated.

The active ingredients in Jaguar, bromoxynil and diflufenican, have some translocation in the target weed but they target photosynthetic processes. If they are translocated into broomrape they are not likely to have a direct affect. However disruption to host photosynthesis may reduce the transfer of carbon to the root system and prevent broomrape development to maturity. Herbicide application can also result in stomatal closure which would also impact broomrape growth. Broadstrike has minimal effect on cretan weed apart from a short-term reduction in growth which could slow down broomrape development. From our 2010 experiment we know that broomrape can emerge from plants sprayed with Brodal (diflufenican) and this did not kill cretan weed so this active ingredient in Jaguar may not be effective for broomrape control. The bromoxynil in Jaguar is the ingredient that has some impact on cretan weed but at sublethal doses we are not sure that it will kill broomrape attachments. However, the bromoxynil and diflufenican may slow down cretan weed growth to such an extent that some Broadstrike is not metabolised and is transported to broomrape.

The most effective means of broomrape control using these products would be to kill cretan weed. At 27 days after Jaguar/BS application not all cretan weed was killed at any of the rates applied so there is still a risk of broomrape emergence from live cretan weed. The model predicts rates of 680 ml ha^{-1} of Jaguar/BS are required to kill cretan weed four weeks after application. Unfortunately the trial was destroyed before further data could be collected so there may have been further mortality of cretan weed. In Rural Solutions' 2009 trial of Jaguar + Broadstrike there was complete death of cretan weed at rates of 500 ml ha^{-1} after only 13 days.

From the limited medic data available, the model predicts that rates of Jaguar/BS up to about 400 ml ha^{-1} have minimal impact on medic condition, at least in the short-term. The impact of Jaguar on medic requires more accurate quantification. Although medic flowered and at least one of the plots sprayed with 400 ml ha^{-1} of Jaguar/BS had large medic plants, we do not know the impacts of the herbicide mixture on medic growth and reproduction. The shape of the dose response curves indicates that with relatively small changes in Jaguar concentration up to 400 ml ha^{-1}, there can be considerable sublethal effects on cretan weed but minimal effects on medic. There is scope to adjust the application rate, provided that broomrape control can be achieved.

As the ingredient diflufenican is not successful for controlling broomrape, a decision needs to be made whether Jaguar/BS increases the spectrum of weeds controlled over Bromoxynil/BS. Results from Rural Solutions 2009 trials found that Jaguar/BS was more damaging to medic and cretan weed than Bromoxynil/BS although bromoxynil rates were higher in the latter treatments. This would suggest that the addition of diflufenican has a synergistic effect on these plants.

18. Medic pasture herbicide field trial

Jane Prider, Andrew Craig

Branched Broomrape Eradication Program

January 2012

Summary

In this field trial and pot experiment we evaluated the efficacy of the herbicides Buttress, Bromoxynil and Jaguar in mixture with Broadstrike for the control of broomrape in medic pastures. Past trials demonstrated these herbicides were effective for the control of cretan weed, a problem broomrape host within pastures throughout the Quarantine Area; however more trial work was required to quantify impacts on medic.

Buttress caused only minor damage to cretan weed. Jaguar provided more effective control of cretan weed than Bromoxynil. The highest Jaguar rate of 500 ml ha^{-1} (with 25 g ha^{-1} Broadstrike) resulted in an 80% decrease in cretan weed cover. Visual damage to medic plants, was visible 12 days after spray application, but plants later recovered. There were no medic deaths but plants sprayed at 500 GDD had 20% less biomass than control plants. The biomass of medic sprayed at 750 GDD did not differ significantly from unsprayed controls. Herbicide applications had no effect on medic pod production. No broomrape emergence occurred in plots sprayed with 500 ml ha^{-1} Jaguar/ Broadstrike. Pot experiments showed that Jaguar/Broadstrike at sub-lethal doses provided some short-term activity, with no broomrape emergence in pots sprayed at 1200 GDD and very reduced emergence in comparison with controls at earlier spray dates.

Recommendations:

- Jaguar at a rate of 500 ml ha^{-1} is recommended for the control of broomrape where cretan weed is a host. In medic pastures with cretan weed, some loss of medic biomass should be expected although individual plants are not expected to be killed nor should pod development be reduced.
- Jaguar is more effective for killing cretan weed when applied at 750 GDD rather than at 500 GDD. Medic damage would also be reduced by spraying at this later date.
- Broadstrike at the rate of 25 g ha^{-1} is added to Jaguar to increase the spectrum of broomrape-host weeds controlled.

Introduction

Pastures present the most challenging situation for broomrape control in the Quarantine Area. Pastures that comprise medic and cretan weed are the most problematic as many of the herbicides that are safe for use on medic, such as Broadstrike, have no activity on cretan weed (Prider & Craig 2010a). As cretan weed is a favoured host for broomrape it is critical that control options are found for this weed.

Recent research work found the herbicide bromoxynil has some efficacy for the control of cretan weed (McInerny 2006, Bolto & Morgan 2009, Prider & Craig 2010b). In two out of three trials there has been almost complete mortality of cretan weed when sprayed with bromoxynil at rates greater than 600 ml ha^{-1} (McInerny 2006, Prider & Craig 2010b). The herbicide Jaguar, which comprises a mixture of bromoxynil and diflufenican, was equally effective at killing cretan weed at rates greater than 400 ml ha^{-1} (Bolto & Morgan 2009, Lamey 2010). Although the rates of bromoxynil used have no lethal effect on medic it is not known whether rates that are effective for the complete control of cretan weed will significantly reduce medic cover or yield. Bromoxynil, applied at the label recommended rate of 1.4 L ha^{-1} has negative impacts on medic although halving label rates can reduce visual symptoms of damage (Valentine and Ferris 2005). It may be possible to use a lower rate and still achieve broomrape control whilst minimising medic impacts. It is not known whether bromoxynil can control broomrape when applied at rates that are sub-lethal to cretan weed although limited data indicates no broomrape emergence occurs when hosts are almost killed (< 10% surviving biomass, Prider & Craig 2010b).

There are limited herbicide choices for medic pastures but 2,4-DB (*e.g.* Buttress®) has shown some effectiveness against cretan weed (Bolto and Morgan, 2009). This herbicide can be damaging to medic when applied at label recommended rates (Sandral et al. 1997, Grichar and Ocumpaugh 2009) although it has been found to be less damaging than bromoxynil (Young et al 1992, Sandral et al 1997). This herbicide has also been used to reduce *Striga* emergence in sorghum (Dembele et al 2005) so could potentially have direct impacts on broomrape.

Objectives

Although our preliminary work has identified some potentially useful products for control of broomrape in medic pastures where cretan weed is present, we need to demonstrate consistent results in different seasons and at different sites. We also need to quantify the effects on medic under field trial conditions. The eradication program needs a clear protocol for herbicide application for broomrape control in medic pasture where cretan weed is present.

The aims of these experiments are:

- To quantify the effects of Jaguar, Bromoxynil and Buttress in mixture with Broadstrike on medic and cretan weed in field trials
- To develop recommendations for the rate and timing of application of these herbicides that maximises cretan weed and broomrape control and minimises medic damage
- To determine if Bromoxynil and Jaguar rates sub-lethal to cretan weed are effective for broomrape control.

The outcomes from this project will enable the eradication program to recommend to landholders a procedure for controlling broomrape in medic pastures where cretan weed is present that will include a suitable herbicide, its application rate and timing and the potential risks to medic production.

Methods

Medic field trials

Medic field trials were conducted at two properties, at Bowhill and the trial site at Brinkley. In each trial paddock an area was selected where medic and cretan weed were present. Broomrape was present at the Brinkley site only. The trial was a complete factorial design with three factors; herbicide, application rate and application timing. Each combination of factors was replicated once in each of four blocks. Each treatment comprised a plot 2 m by 15 m separated from neighbouring plots by a 1 m buffer.

The levels of each of the experimental factors were:

1. Herbicide: Bromicide 200, Jaguar, Buttress
2. Application rate:
    a) Bromicide : 500, 600, 700 ml ha^{-1}
    b) Jaguar: 300, 400, 500 ml ha^{-1}
    c) Buttress: 2, 2.5, 3.5 L ha^{-1}
    All herbicides were applied in mixture with Broadstrike at a rate of 25 g ha^{-1} and the adjuvant Enhance (500 ml ha^{-1}).
3. Application timing: 500 or 750 GDD

Site formed another factor in the experiment with two levels; Bowhill and Brinkley.

The control plots comprised one unsprayed plot in each block. The treatment plots were sprayed using a 2 m wide boom spray attached to a quad bike. The first spray was on 13/7/11 at Brinkley and 14/7/11 at Bowhill. There was some light rain at the Brinkley site during spraying of Jaguar and Bromicide. The second spray was on the 11-12/8/11 at Brinkley and Bowhill respectively. It was fine at Brinkley but overcast during spraying at Bowhill.

The following response variables were measured at time intervals after spraying as indicated:

1. Visual assessment of herbicide damage: 12 days after spraying we photographed representative medic and cretan weed plants in each plot and made a visual assessment of medic and cretan weed damage. This followed a point scoring system ranging from 10 for no damage to 0 for complete death (see Appendix A).
2. Survival : 20 cretan weed and medic plants were randomly selected in each plot immediately after spraying. and marked with paint so they could be relocated. The number of surviving plants was counted 20 days and 50 days after spraying.
3. Cover: The presence/absence of cretan weed and medic in 10 by 10 cm divisions of a 50 by 50 cm plot was counted at spray application then 30 days and 60 days after spraying. A percentage estimate of cover was derived from this score.
4. Medic yield: To assess herbicide effects on medic production we harvested above-ground biomass from a 25 by 25 cm subplot in each plot 50 days after spraying. We made separate harvests for the two common medic species present, strand medic (*Medicago littoralis*) and burr medic (*M. polymorpha*). We also visually estimated the percentage cover of biomass in the harvest subplot. The biomass was dried and then weighed. At the end of the growing season we harvested one strand and one burr medic plant from each plot. After the plants were dried, the pods were separated from the stem material, counted and weighed.
5. Broomrape emergence: At the Brinkley site we counted the number of emerged broomrape plants in a randomly selected 1 m by 1 m subplot in each treatment plot. We also counted the number of emerged plants in a 1 m^2 subplot in the unsprayed buffer zone adjacent to each treatment plot.

Pot experiment

A pot experiment tested whether sub-lethal doses of the herbicides Bromoxynil and Jaguar provide effective broomrape control on cretan weed hosts. The experiment was conducted in pots at the Mannum Trial Site. This enabled us to control the densities of broomrape and cretan weed.

We prepared 200 mm pots by filling the bottom 2/3 with field soil from the trial site and then adding 1 ml of broomrape seed mixed with field soil and 15 ml Osmocote® slow-release fertiliser to fill the pots. Cretan weed seed was sown into each pot. Early sowings of cretan weed on 6/6/11 failed so pots were resown on 27/7/11.

The experiment was a full factorial design with three factors; herbicide, application rate and application timing. We used Bromoxynil applied at rates of 150, 300 and 500 ml ha^{-1} and Jaguar at rates of 100, 250 and 400 ml ha^{-1}. These herbicides were mixed with Broadstrike at a constant rate of 25 g ha^{-1} and the adjuvant Bonza at the rate of 500 ml ha^{-1}. Herbicides were applied with a hand boom spray at one of three different timings; 600, 900 or 1200 GDD. There were five replicates of each treatment plus a set of unsprayed controls.

When broomrape plants emerged we washed the soil from the cretan weed roots and counted the number of live and dead broomrape attachments on each plant under a microscope. We recorded the number of broomrape plants in each developmental stage from small attachment to flowering.

Analysis

Details of statistical analysis methods and all statistical results tables are included in Appendix B.

Results

Visual damage

Herbicide damage was detectable on medic plants 12 days after application. It ranged from minor damage, present as small necrotic spots on medic leaves sprayed with Buttress, to bleaching of entire leaves over half of the plant with high application rates of Bromicide or Jaguar (

Figure 6). Control plants had none of these symptoms. There were some differences in the amount of visual damage resulting from the different herbicides related to site and spray timing (

Figure 7). Condition scores for Buttress did not differ from controls. High rates of Jaguar were more damaging than Bromicide applied at the lowest rate. More herbicide damage occurred after the 500 GDD spray but only at the Bowhill site. In addition, Bromicide caused more damage when sprayed at 500 GDD than at 750 GDD.

Cretan weed plants sprayed with Buttress showed no herbicide damage after the first spray but some minor damage after the second spray at rates of 2.5 – 3.5 L ha^{-1} (

Figure 7). Bromicide and Jaguar caused visual damage to cretan weed at all application rates on both spray dates. This ranged from necrosis of leaf tips and edges and leaf bleaching to partially dead leaves and death of most of the leaves to the base of the rosette (

Figure 6).

A B C

Figure 6. Examples of herbicide damage to medic plants (top) and cretan weed (bottom) sprayed with A) Buttress, B) Bromicide and C) Jaguar.

Survival

Very few medic plants died and those deaths occurred in control plots as well as sprayed plots.

There was no cretan weed death in plots sprayed with Buttress or control plots. Jaguar was more effective at killing cretan weed than Bromicide (

Figure 8). Overall there was 66% cretan weed survival in Bromicide plots and 23% survival in Jaguar plots. For both herbicides, high application rates were more effective than low to medium rates and there was an increase in cretan weed deaths between 20 and 50 days. There was no significant difference in cretan weed survival between the two spray timings or between sites. There was a trend for reduced survival at the later spray date (750 GDD) than the earlier spray date at 500 GDD. There was also a trend for higher mortality at Brinkley, where cretan weed was very dense, but only in plots sprayed with Jaguar.

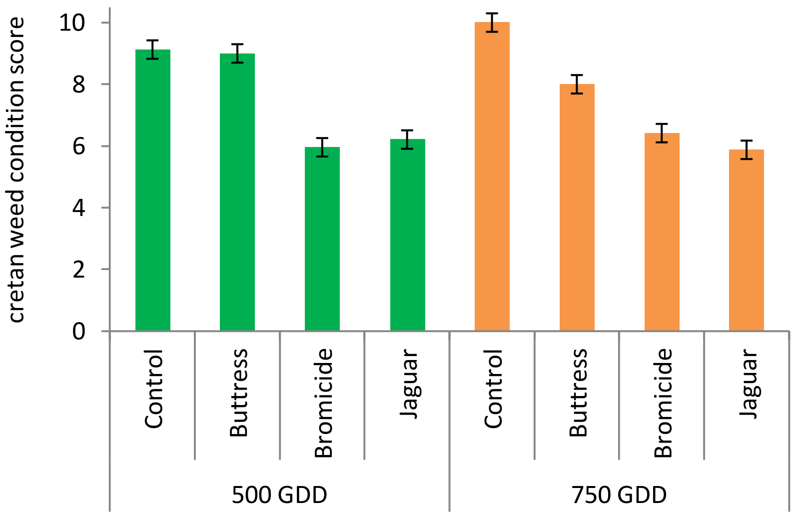

Figure 7. Condition scores for medic (top) and cretan weed (bottom) sprayed with herbicides at two spray timings. Bars show means ± LSD (α = 0.5) calculated from the model (pooled across rates, n = 12). Statistical results are in Appendix B Table 1and Table 2.

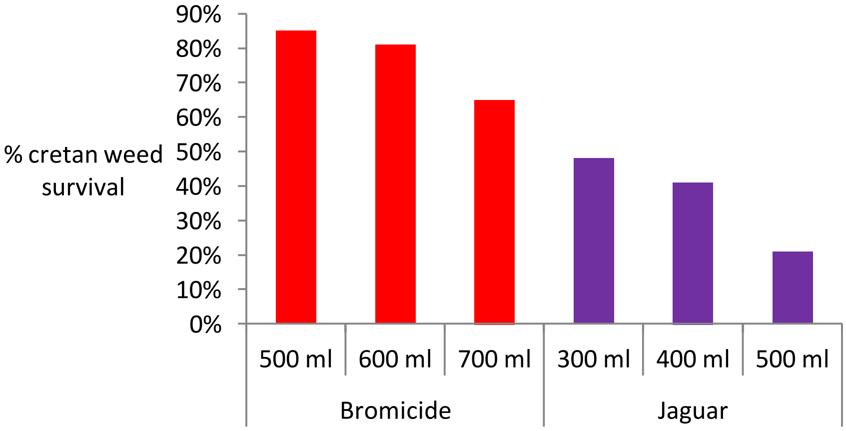

Figure 8. Cretan weed survival 50 days after spraying with Bromicide or Jaguar herbicide, pooled across both sites and spray dates. Bars show mean calculated from the model (n = 16). Statistical results in Appendix B Table 3.

Cover

Cretan weed cover decreased in plots sprayed with Bromicide or Jaguar at both spray timings. Jaguar sprayed at 400 or 500 ml ha^{-1} produced the greatest decrease in cretan weed cover, which had decreased by approximately 80% after 60 days (

Figure 9). Bromicide application resulted in decreases in cretan weed cover of 40 % after 60 days. Cretan weed cover increased after 30 days in control plots and Buttress plots that were sprayed at 500 GDD, as early in the season cretan weed rosettes were still expanding. However , after the 750 GDD application there was a 20% decrease in cretan weed cover in plots sprayed with Buttress at rates of 2.5 and 3.5 L ha^{-1}.

Medic increased in cover in all plots over the course of the trial, with the exception of an initial decrease in cover in plots sprayed with 500 ml ha^{-1} of Jaguar at Brinkley. By 60 days after spraying medic cover in these plots had increased similarly to other plots at Brinkley. Cover of medic was variable across the two sites and although the analysis accounted for this by modelling the relative increase in medic cover we did not detect any difference between herbicides or application rates (

Figure 10). There were differences between sites and between sampling times but only following spraying at 500 GDD. Increase in medic cover was greater at Bowhill than Brinkley and for the initial 30 days following the 500 GDD spraying.

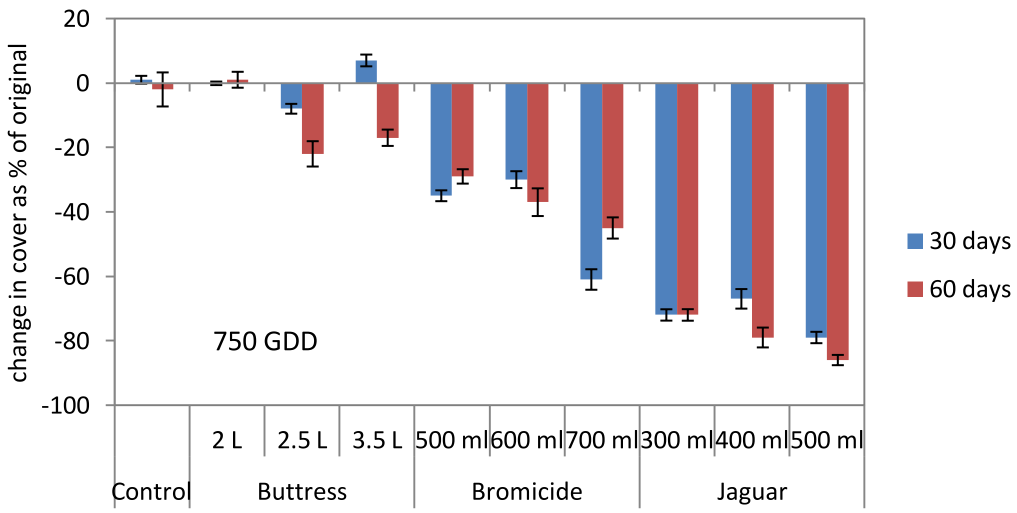

Figure 9. Change in cretan weed cover following spraying with herbicides at two timings, 500 GDD (top) and 750 GDD (bottom). Each bar represents the mean ± 1 SE (pooled across sites, n = 8). Statistical results in Appendix B Table 4.

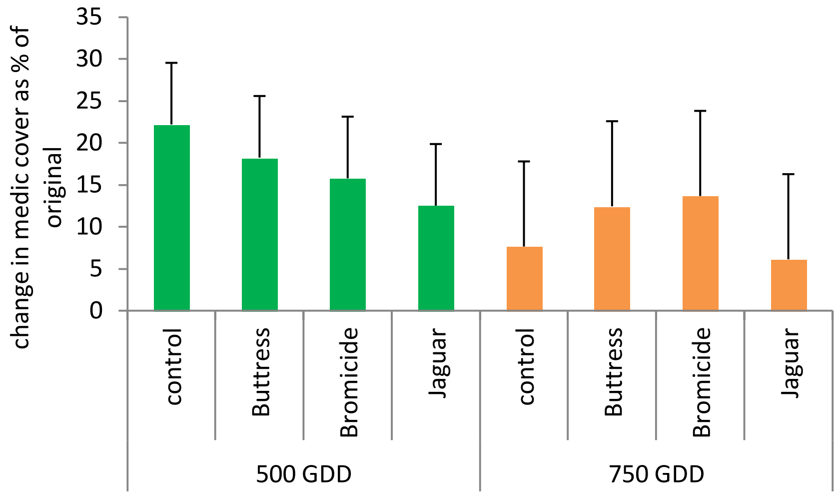

Figure 10. Change in medic cover following spraying at two timings. Data pooled across sites, application rates and sampling times. Each bar represents the mean ± LSD (α = 0.05) calculated from the model (n = 24). Data for each spray timing were fitted to a separate model. Statistical results in Appendix B Table 5 and Table 6.

Biomass

Medic sprayed with either Bromicide or Jaguar at 500 GDD had approximately 20 % less biomass than controls or plants sprayed with Buttress (

Figure 11). Increasing rates of these two herbicides did not result in further reductions in biomass. Medic sprayed with all herbicides at 750 GDD had approximately 10% less biomass than controls but the difference was not significant (

Figure 11). At this spray date there was less biomass at the Brinkley site than the Bowhill site and the burr medic had greater biomass than strand medic, however these differences were consistent across herbicide treatments.

Herbicide treatments had no significant effect on the dry weight of seed pods produced per plant. Burr medic produced more pod biomass than strand medic but only at the Bowhill site (Statistical results in Appendix B Table 9). There were no consistent differences between herbicide treatments in the number of pods produced per plant, *e.g.* the lowest number of pods were produced in the control and Jaguar 400 ml ha^{-1} plots (

Figure 12). Much fewer pods were produced at the Brinkley site (mean of 10 per plant) than the Bowhill site (mean of 28 per plant).

Figure 11. Biomass of medic in plots sprayed with herbicides harvested 50 days after treatment. Means have been calculated from the ANCOVA model therefore are adjusted for medic cover in

each sampled plot (sites and rates pooled, n = 24). Statistical results in Appendix B Table 7and

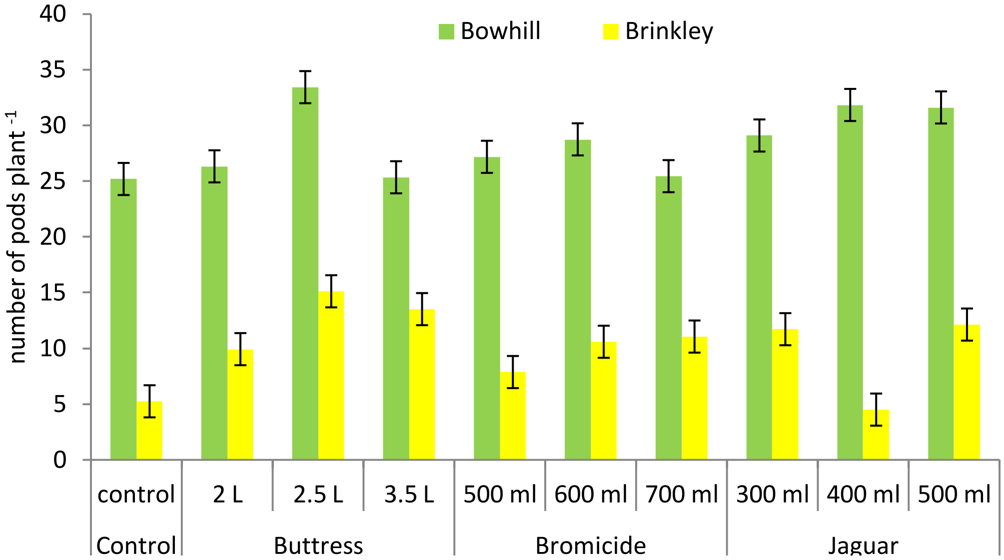

Figure 12. Number of pods produced by sampled medic plants (burr and strand medic data combined) in different herbicide treatments at the two sites. Spray timings have been pooled. Bars are means ± LSD (α = 0.05) for each plot (n=8) estimated from the ANCOVA model therefore adjusted for plant size. Statistical results in Appendix B Table 10.

Broomrape Emergence

Herbicide applications and their timing had a significant effect on broomrape emergence (

Figure 13). Broomrape emerged in most buffer zones adjacent to sprayed plots. The least emergence occurred in plots sprayed with Jaguar, with no emergence in plots sprayed at 500 ml ha^{-1}. For Jaguar, there was no significant difference in emergence at either spray timing or at any of the applied rates. There was less emergence in plots sprayed at 750 GDD with Bromicide than plots sprayed at 500 GDD. There was higher emergence in plots sprayed with Buttress although emergence was lower than in buffer zones. For Buttress, there was no increased control of emergence with increasing rates of Buttress, indicating that the Broadstrike in the mix was active against broomrape rather than Buttress.

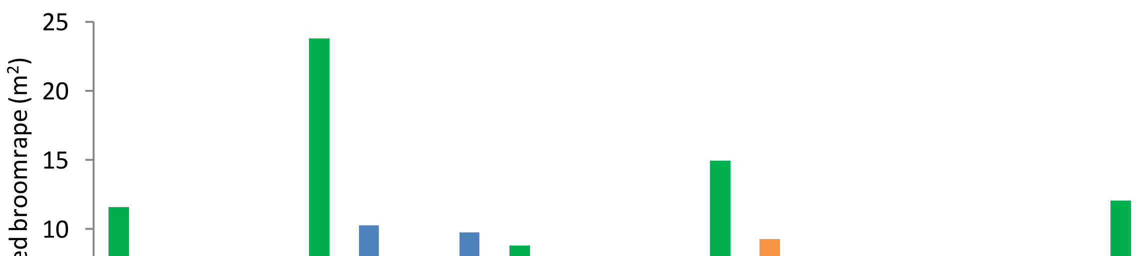

Figure 13. Emergence of broomrape in plots sprayed with herbicides at Brinkley. Each bar is the mean calculated from the data (n = 4). Statistical results in Appendix B Table 11.

Pot experiment

With sub-lethal doses of Bromoxynil or Jaguar (in mixture with Broadstrike), broomrape emergence was significantly reduced in comparison with controls (

Figure 14). When pots were sprayed early at 600 GDD some hosts were killed, even at the low application rates used. Plants that survived these herbicide applications had emerged broomrape. Bromoxynil was more effective at preventing broomrape emergence than Jaguar when pots were sprayed at 600 GDD but only at the highest application rate. This was the result of host death in all but the lowest Bromoxynil application rate.

Jaguar was more effective at preventing emergence than Bromoxynil when sprayed at 1200 GDD at the medium to high rates. Emergence occurred at all application rates of both herbicide types when sprayed midway through the growth-season at 900 GDD. There was no difference between rates applied, indicating that it was possibly the Broadstrike that was active against broomrape. However counts of the number of broomrape attachments reveal a significant rate effect. Pots sprayed at 900 GDD had a similar proportion of live broomrape attachments as controls. Pots sprayed at 1200 GDD had a lower proportion of live attachments and this effect was dependent on the rate of herbicide applied. Pots that received high rates of Bromoxynil or Jaguar had a lower proportion of live attachments (

Figure 15).

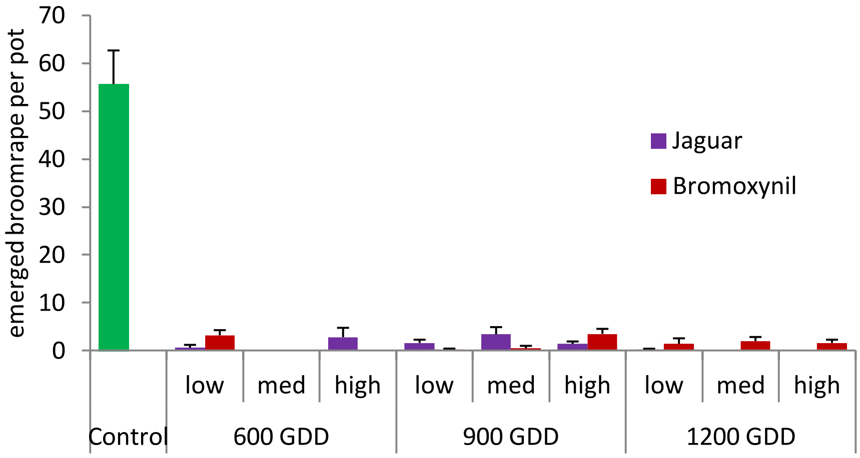

Figure 14. Number of emerged broomrape in pots sprayed with herbicides at different rates and application timings. Bars represent the mean ± 1 SE calculated from the raw data (n = 5). Statistical results in Appendix B Table 12.

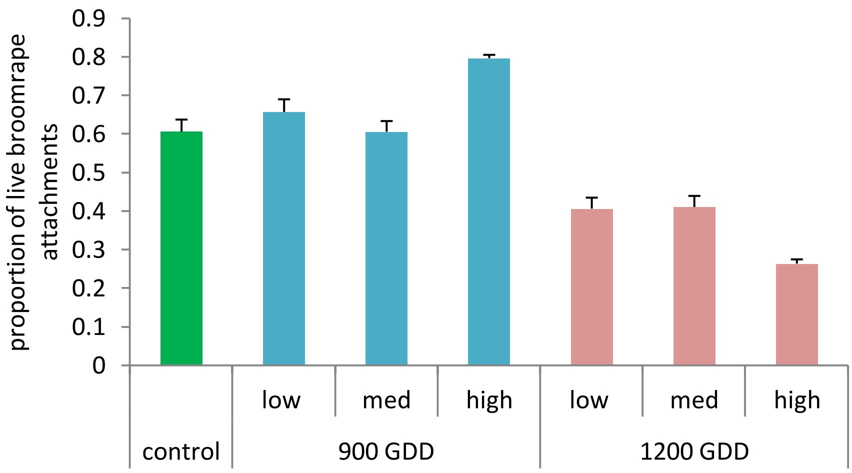

Figure 15. Proportion of live attachments (emerged and un-emerged stages) in pots sprayed at different rates and application timings (pooled across both herbicides). Bars represent the mean ± 1 SE calculated from the raw data (n = 5). Statistical results in Appendix B Table 13.

Discussion

Of the herbicides trialled, Jaguar was more effective at controlling cretan weed than Bromicide or Buttress. Buttress caused only minor damage to cretan weed so can be considered to be ineffective against this weed. This result is contrary to 2009 trial results where Rural Solutions recorded a 56% reduction in cretan weed with a 2.5 L ha^{-1} application of Buttress with 25 g ha^{-1} Broadstrike (Bolto & Morgan 2009).

Although Jaguar rates as low as 300 ml ha^{-1} provided some cretan weed control, rates of 500 ml ha^{-1} killed up to 90% of cretan weed plants resulting in 80% reductions in cretan weed cover. These results are consistent with field trials by Rural Solutions in 2009 where Jaguar/Broadstrike (500 ml/25 g ha^{-1}) resulted in a 100% decrease in cretan weed biomass and Jaguar alone at 500 ml ha^{-1} resulted in a 75% decrease in biomass (Bolto & Morgan 2009). From another trial in 2010 (Lamey 2010) it was predicted that a Jaguar dose of 620 ml ha^{-1} would be required for 100% cretan weed kill and a dose as low as 260 ml ha^{-1} would result in 50% mortality (Prider 2011). From this series of trials we can conclude that Jaguar applied at a rate of 500 ml ha^{-1} consistently provides cretan weed control, achieving high mortality and reduction in cover or biomass of between 75 and 100%.

These rates are also adequate for prevention of broomrape emergence, although data is limited by availability of field trial sites for this work. Given the poor activity of Broadstrike for broomrape control on cretan weed, prevention of emergence was most likely achieved through the reduction in cretan weed cover. However some cretan weed survived in sprayed plots. Our pot experiments showed that doses of Jaguar sub-lethal to cretan weed also provide some broomrape control independent of the effects of Broadstrike in the mixtures. We found a proportion of dead broomrape attachments observed on cretan weed sprayed with high rates of Jaguar compared to lower rates. Although the use of Jaguar alone could achieve some broomrape control in pastures with cretan weed, Broadstrike in the mixture would achieve a broader spectrum of weed control. We know that Broadstrike is effective for broomrape control on cape weed and turnip weed hosts (Prider & Craig 2010b).

Visually, Bromicide had similar damaging effects on cretan weed but this herbicide did not result in as high a mortality rate as Jaguar. Although this herbicide performed as well as Jaguar in pots for control of broomrape it has inconsistent efficacy in the field for cretan weed control.

We recorded less damage to medic than in previous trials although the methods used in this trial were more quantitative. Visually, up to 50% of medic biomass was affected by herbicides, a similar figure as the visual estimates by Rural Solutions in their trials (55-60%) (Bolto and Morgan 2009). However, this did not translate to difference in dry weight or pod production. We found that medic recovered from initial herbicide damage. Higher rates of the herbicides did not result in increased damage or loss of biomass. Some loss of biomass would occur with Jaguar use and a conservative estimate of up to 20% biomass loss is predicted. Grazing (possibly by mice) at Brinkley and some short-term grazing by sheep at Bowhill may have affected these results. Control and sprayed plants were grazed, resulting in considerable variance in cover measurements which affected statistical comparisons.

More visual damage to medic was observed at the Bowhill site but plants at this site had a greater increase in cover after the 500 GDD spray and also produced more biomass and pods than medic at the Brinkley site. This reflects more optimal conditions for growth at the Bowhill site. Overall, growth of medic at both sites was very poor for the duration of this trial. At Brinkley, medic and cretan weed plants were smaller in 2011 than in 2010. Dry periods in April-May and in September may have resulted in poor growth.

The later spray date of 750 GDD is recommended in preference to the earlier date of 500 GDD. We recorded less damage to medic and larger decreases in cretan weed following the herbicide application at 750 GDD. Where full cretan weed control is not expected then an even later spray date of 1200 GDD would also control broomrape by killing attachments without necessarily killing the host, as demonstrated in the pot experiment.

Recommendations

- Jaguar at a rate of 500 ml ha^{-1} is recommended for the control of broomrape where cretan weed is a host. In medic pastures with cretan weed, some loss of medic biomass should be expected although individual plants are not expected to be killed nor should pod development be reduced.

- Jaguar is more effective for killing cretan weed when applied at 750 GDD rather than at 500 GDD. Medic damage would also be reduced by spraying at this later date.
- Broadstrike at the rate of 25 g ha^{-1} is added to Jaguar to increase the spectrum of broomrape-host weeds controlled.
- Jaguar/Broadstrike provides control of broomrape at doses sub-lethal to cretan weed but the effect of the herbicides is short-term and complete control will not be achieved with early spray applications (before 1200 GDD).

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Appendix: Statistical results

Visual damage

Condition scores for medic and cretan were fitted separately to an ANOVA (Analysis of Variance) model testing for the effects of site, herbicide treatment, application rate and timing and their interactions.

Medic visual damage condition score

Table 1. Results of ANOVA testing the effects of site, spray timing (GDD), herbicide treatment and rate on medic condition. Non-significant interactions and main effects have been removed from the model.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Site	1	10	10	21.4	<.001
GDD	1	0.9	0.9	1.93	0.168
Herbicide	3	426.025	142.0083	303.89	<.001
Rate	3	15.9306	5.3102	11.36	<.001
GDD.Herbicide	3	10.5167	3.5056	7.5	<.001
GDD.Rate	3	0.875	0.2917	0.62	0.601
Site.GDD	1	3.025	3.025	6.47	0.012
Herbicide.Rate	3	3.0694	1.0231	2.19	0.092
Site.Herbicide	3	1.1667	0.3889	0.83	0.478
Site.Rate	3	1.6806	0.5602	1.2	0.313
Site.Herbicide.Rate	3	3.9028	1.3009	2.78	0.043
Residual	132	61.6833	0.4673		
Total	159	538.775			

Cretan weed visual damage condition score

Table 2. Results of ANOVA testing the effects of spray timing (GDD), herbicide treatment and rate on cretan weed condition. Data has been pooled across the two sites. Non-significant interactions and main effects have been removed from the model.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GDD	1	1.225	1.225	2.28	0.133
Herbicide	3	283.9333	94.6444	176.08	<.001
Rate	3	17.6806	5.8935	10.96	<.001
GDD.Herbicide	3	17.6917	5.8972	10.97	<.001
GDD.Rate	3	1.5417	0.5139	0.96	0.415
Herbicide.Rate	3	2.4861	0.8287	1.54	0.206
GDD.Herbicide.Rate	3	13.2917	4.4306	8.24	<.001
Residual	140	75.25	0.5375		
Total	159	413.1			

Survival

Percentage survival was calculated from the counts of dead cretan weed and medic plants after 20 days and 50 days. There were very few deaths of medic, or cretan weed in the Buttress or control treatments, so these data were not included in the analysis. Data for cretan weed survival in the Bromicide and Jaguar treatments were arcsin-transformed to meet the assumptions of normality and homogeneity of variances for a repeated measures ANOVA. This analysis tested for the effects of herbicide, rate, spray timing, and site on cretan weed survival. The two score times at 20 and 50 days after spraying were the repeated measures factor in this model.

Cretan weed survival

Table 3. Results of repeated measures ANOVA testing the effects of spray timing (GDD), herbicide type (Jaguar or Bromicide) and rate on cretan weed survival measured at 20 days and 50 days after spraying (time). Non-significant interactions and main effects have been removed from the model.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Main model effects					
Herbicide	1	9.82851	9.82851	62.21	<.001
Rate	2	2.06323	1.03162	6.53	0.002
GDD	1	0.33204	0.33204	2.10	0.151
Residual	91	14.37773	0.15800	7.05	
Repeated measures effects					
Time	1	4.21650	4.21650	188.21	<.001
Time.Herbicide	1	0.07523	0.07523	3.36	0.070
Time.Rate	2	0.04916	0.02458	1.10	0.338
Time.GDD	1	0.03837	0.03837	1.71	0.194
Residual	91	2.03864	0.02240		
Total	191	33.01942			

Cover

Frequency counts for cretan weed and medic plants in each plot were converted to proportions and the change in cover between Day 0, when plants were sprayed, and Day 30 and Day 60 was calculated. The change in cover was expressed as a percentage of the original cover at Day 0 to account for variability in cover across the plots. These values were log- (medic) or arsin-(cretan weed) transformed to meet the assumptions of normality and homogeneity of variances for a repeated measures ANOVA. Cover at 30 days and 60 days were the repeated measures factor in separate models for medic and cretan weed. For cretan weed, data from sites were pooled as there was no significant difference between sites. The model tested the effect of spray timing, herbicide treatment and application rate on change in plant cover. For medic, separate analyses were run for each spray timing as medic plants had almost completed growth expansion by 750 GDD therefore less expansion in cover was expected independent of experimental treatments. The medic models tested the effects of herbicide treatment, application rate and site on change in cover.

Cretan weed cover

Table 4. Results of repeated measures ANOVA testing the effects of spray timing (GDD), herbicide treatment and rate on cretan weed cover measured at 30 days and 60 days after spraying (time). Non-significant interactions and main effects have been removed from the model.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Main model effects					
GDD	1	3.15288	3.15288	10.06	0.002
Herbicide	3	55.20348	18.40116	58.73	<.001
Rate	3	4.10779	1.36926	4.37	0.006
Residual	152	47.62818	0.31334	4.44	
Repeated measures effects					
Time	1	1.67276	1.67276	23.69	<.001
Time.GDD	1	0.33815	0.33815	4.79	0.03
Time.Herbicide	3	0.53569	0.17856	2.53	0.059
Time.Rate	3	0.28412	0.09471	1.34	0.263
Residual	150	10.59102	0.07061		
Total	317	118.7104			

Medic cover- 500 GDD

Table 5. Results of repeated measures ANOVA testing the effects of site, herbicide treatment and rate on medic cover measured at 30 days and 60 days after spraying (time) at 500 GDD.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Main model effects					
Herbicide	3	0.211024	0.070341	5.52	0.002
Rate	3	0.026408	0.008803	0.69	0.561
Site	1	0.576578	0.576578	45.28	<.001
Herbicide.Rate	3	0.040776	0.013592	1.07	0.37
Herbicide.Site	3	0.004982	0.001661	0.13	0.942
Rate.Site	3	0.000293	0.000098	0.01	0.999
Herbicide.Rate.Site	3	0.150896	0.050299	3.95	0.012
Residual	60	0.763938	0.012732	5.45	
Repeated measures effects					
Time	1	0.418444	0.418444	179.06	<.001
Time.Herbicide	3	0.009449	0.00315	1.35	0.267
Time.Rate	3	0.002887	0.000962	0.41	0.745
Time.Site	1	0.000278	0.000278	0.12	0.731
Time.Herbicide.Rate	3	0.006178	0.002059	0.88	0.456
Time.Herbicide.Site	3	0.014684	0.004895	2.09	0.11
Time.Rate.Site	3	0.001705	0.000568	0.24	0.866
Time.Herbicide.Rate.Site	3	0.016495	0.005498	2.35	0.081
Residual	60	0.140216	0.002337		
Total	159	2.385231			

Medic cover- 750 GDD

Table 6. Results of repeated measures ANOVA testing the effects of site, herbicide treatment and rate on medic cover measured at 30 days and 60 days after spraying (time) at 750 GDD. Non-significant interactions have been removed from the model.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Main model effects					
Herbicide	3	0.15573	0.05191	1.63	0.191
Rate	3	0.05602	0.01867	0.58	0.627
Site	1	0.0224	0.0224	0.7	0.405
Residual	72	2.29845	0.03192	3.16	
Repeated measures effects					
Time	1	0.00054	0.00054	0.05	0.818
Time.Herbicide	3	0.07463	0.02488	2.46	0.069
Time.Rate	3	0.01025	0.00342	0.34	0.798
Time.Site	1	0.02055	0.02055	2.03	0.158
Residual	72	0.72745	0.0101		
Total	159	3.36603			

Medic biomass

The data from the two spray timings were analysed separately as harvests were made at different times which may have affected biomass production independent of experimental treatments. Biomass dry weights were square-root transformed to meet assumptions of normality and homogeneity of variances for an ANCOVA. The covariate in the ANCOVA model was the estimated percentage cover of medic in the harvested plot. The model tested for the effects site, herbicide and rate on the biomass of the two medic species.

For the pod data, the values were log-transformed to meet the assumptions of normality and homogeneity of variances in an ANCOVA (Analysis of Covariance) model. The co-variate in this model was the stem dry weight. We tested the effects of site, herbicide, rate and spray timing on pod number and pod weight of the two medic species.

Medic biomass – 500 GDD

Table 7. Results of ANCOVA testing the effects of site, herbicide treatment and rate on biomass of two medic species harvested 50 days after spraying at 500 GDD. Medic cover was used as a covariate in the model. Non-significant interactions have been removed from the model.

Source of variation	d.f.	s.s.	m.s.	v.r.	cov.ef.	F pr.
Herbicide	3	1.5435	0.5145	2.64	1.00	0.052
Rate	3	0.2400	0.0800	0.41	1.00	0.746
Site	1	0.4369	0.4369	2.24	0.95	0.137
Species	1	0.0497	0.0497	0.25	1.00	0.615
Covariate	1	34.6578	34.6578	177.54		<.001
Residual	149	29.0872	0.1952		2.18	
Total	158	69.8731				

Medic biomass – 750 GDD

Table 8. Results of ANCOVA testing the effects of site, herbicide treatment and rate on biomass of two medic species harvested 50 days after spraying at 750 GDD. Medic cover was used as a covariate in the model. Non-significant interactions have been removed from the model.

Source of variation	d.f.	s.s.	m.s.	v.r.	cov.ef.	F pr.
Herbicide	3	0.7214	0.2405	1.44	1.00	0.233
Rate	3	0.2865	0.0955	0.57	1.00	0.634
Site	1	2.0605	2.0605	12.36	1.00	<.001
Species	1	0.8174	0.8174	4.91	0.98	0.028
Covariate	1	48.1016	48.1016	288.64		<.001
Residual	150	24.9969	0.1666		2.90	
Total	159	77.4223				

Medic pod biomass

Table 9. Results of ANCOVA testing the effects of site, herbicide treatment, rate and spray timing (GDD) on biomass of pods of two medic species. Medic stem biomass was used as a covariate in the model. Non-significant interactions have been removed from the model.

Source of variation	d.f.	s.s.	m.s.	v.r.	cov.ef.	F pr.
Herbicide	3	1.2785	0.4262	1.39	1	0.245
Rate	3	0.2934	0.0978	0.32	1	0.811
Site	1	10.6817	10.6817	34.9	0.89	<.001
Species	1	40.7827	40.7827	133.25	0.92	<.001
GDD	1	0.218	0.218	0.71	1	0.399
Site.Species	1	11.4099	11.4099	37.28	1	<.001
Covariate	1	96.8624	96.8624	316.48		<.001
Residual	308	94.2677	0.3061		2.02	
Total	319	294.6731				

Medic pod number

Table 10. Results of ANCOVA testing the effects of herbicide type, rate and site on number of pods of two medic species pooled across spray timings (GDD). Medic stem biomass was used as a covariate in the model.

Source of variation	d.f.	s.s.	m.s.	v.r.	cov.ef.	F pr.
Herbicide	3	2.3483	0.7828	2.83	1	0.038
Rate	3	0.2918	0.0973	0.35	1	0.788
Site	1	16.2111	16.2111	58.71	0.89	<.001
Species	1	79.393	79.393	287.52	0.92	<.001
Herbicide.Rate	3	2.2985	0.7662	2.77	1	0.042
Herbicide.Site	3	1.5288	0.5096	1.85	0.99	0.139
Rate.Site	3	0.5092	0.1697	0.61	1	0.606
Herbicide.Rate.Site	3	2.8522	0.9507	3.44	0.99	0.017
Covariate	1	92.7998	92.7998	336.07		<.001
Residual	298	82.2868	0.2761		2.12	
Total	319	232.1388				

Broomrape emergence

These data were analysed using a negative binomial Generalised Linear Model (GLM). Broomrape emergence in unsprayed buffers was included as a herbicide treatment with a rate of zero in the analysis. The effects tested were herbicide, application rate and spray timing. Interactions between factors that were not significant were iteratively removed from the model in a 'topdown' stepwise procedure (i.e. the initial model includes all interaction terms which are subsequently removed if not significant). At each step in the procedure, the difference between the residual deviance at each subsequent step of the model was tested with a chi-square test. If the chi-square test was not significant the term could be removed from the model.

Broomrape emergence - Brinkley

Table 11. Results of negative binomial GLM testing the effects of herbicide type, rate and spray timing (GDD) on the number of emerged broomrape in plots at the Brinkley site.

Model term	Res df	Res dev	Δdf	ΔRes dev	χ^2 P approx
constant	143	536.5			
herbicide	141	529.3	2	7.3	0.026
rate	138	464.1	3	65.2	<0.001
GDD	137	462	1	2.1	0.143
Herbicide.Rate	131	416.2	6	45.8	<0.001
Herbicide.GDD	129	400.9	2	15.2	<0.001
Rate.GDD	126	398.5	3	2.5	0.478
Herbicide.Rate.GDD	120	374	6	24.5	<0.001

Broomrape in pots

Numbers of emerged broomrape plants in each herbicide-treated pot were fitted to a poisson GLM with a log link. Controls were not included. Model fitting and simplification proceeded as described for the previous GLM. We tested the effects of herbicide type, application rate and timing and their interactions on broomrape emergence. We calculated the proportion of live attachments retrieved from pots that were at later developmental stages (Stages 4-6, Stage 4 has developed roots, Stage 6 is emerged). Smaller earlier stages were not included in this analysis as they may be overlooked during counting. We fitted these data to an ANOVA model testing the effects of herbicide type, application rate and timing and their interactions on the proportion of live attachments. This analysis included unsprayed controls.

Broomrape emergence

Table 12. Results of poisson GLM testing the effects of herbicide type, rate and spray timing (GDD) on the number of emerged broomrape in pots of cretan weed at Mannum.

Model term	Res df	Res dev	Δdf	ΔRes dev	χ^2 P approx
Full model	72	179			
Main effects					
Herbicide+Rate+GDD	84	274.9			
GDD	86	305.6	2	20.7	<0.001
Rate	86	275.8	2	1.1	0.577
Herbicide	85	284.1	1	9.2	0.002
Interactions					
Herbicide.Rate.GDD	76	212	4	33	<0.001
Rate.GDD	80	252.5	4	40.5	<0.001
Herbicide.GDD	78	233.1	4	21.1	<0.001
Herbicide.Rate	78	214.8	2.8	4	0.592

Broomrape attachments

Table 13. Results of ANOVA testing the effects of herbicide treatment, rate and spray timing (GDD) on the proportion of live broomrape (unemerged and emerged) in pots of cretan weed at Mannum.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Herbicide	1	0.3561	0.3561	2.91	0.093
Rate	3	0.1426	0.0475	0.39	0.761
GDD	2	2.8022	1.4011	11.47	<.001
Rate.GDD	1	0.6019	0.6019	4.93	0.03
Residual	62	7.5757	0.1222		
Total	69	11.4785			

19. When do we need to spray twice?

Jane Prider

Branched Broomrape Eradication Program

January 2011

Summary

Long growing seasons, where break of seasons occur early and rainfall continues into spring, provide challenges for broomrape control. A single spray at the optimum time may not be sufficient to control broomrape plants that attach and hence emerge later in the season, if conditions are suitable. This analysis of rainfall records determines how frequently these seasonal conditions occur in the area affected by broomrape and when a double spray to control broomrape would be necessary.

This analysis is based on the definitions of rainfall criteria in Huda *et al.* 1993 "Assessing and managing cropping risks in low rainfall areas of southern Australia using agroclimatic data". I used the Murray Bridge daily rainfall set with 124 years of data (see Appendix). For GDD, I used the soil temperature data for 3-4 sites (Mypolonga, Caurnamont, Swan Reach, Mannum) from 2000-2008, averaged across sites.

This analysis suggests that double spraying is required when there are opening rains before April 30th, provided there are follow up rains. This will occur two to three times per ten year period (27% of years). The first spray could occur from June (dependent on GDD calculations) and the second spray would occur in late August. The following definitions are used:

- Opening rains are defined as a total of 25 mm over a 14 day period after April 1st. The date is the end of the accumulation of 25 mm.
- Follow-up rains are defined as at least 5 mm of rain falling in each week for any two weeks in the four week period immediately after the break.

How is the date of opening rains defined?

Huda *et al.* used 3 definitions for opening season rains:

1. 10 mm in one day after April 1st
2. 10 mm over two days after April 1st
3. 25 mm over 5 days after April 1st

The broomrape program uses 25 mm over a two week period after April 1st to define opening rains. I compared three calculations for defining opening rains to confirm this.

1. 10 mm over two days after April 1st
2. 25 mm over 5 days after April 1st
3. 25 mm over 14 days after April 1st

Table 1. Percentage of years in which opening rains occur after April 1st by a given date

Date	10 mm in 2 days	25 mm in 5 days	25 mm in 14 days
30-Apr	55%	23%	39%
31-May	81%	46%	69%
30-Jun	94%	59%	85%

The “10 mm in 2 days” definition predicts opening rains will occur in April in 55 % of years (Table 1). The “25 mm in 5 days” prediction appears a little conservative as it predicts that in 41% of years there will be no opening rains before June 30th. In many years there are no opening rains defined by this method.

I looked at how frequently these events may prove to be false starts. This is where the season break was followed by a period of 4 weeks where less than 5 mm fell in each week for any two week period.

Table 2. Percentage of years in which opening rains by given date after April 1st are not succeeded by follow-up rains

date	10 mm in 2 days	25 mm in 5 days	25 mm in 14 days
15-Apr	44%	29%	36%
30-Apr	35%	25%	31%
15-May	31%	20%	31%
31-May	29%	16%	26%
15-Jun	27%	15%	23%
30-Jun	27%	17%	24%

The “10 mm in 2 days” predicts that in 44% of cases, a rainfall event before April 15th was a false break, *i.e.* followed by a period with little or no rainfall. This percentage is reduced where opening breaks include at least 25 mm of rainfall.

Anna Williams and Mark Habner did a count back from broomrape survey start dates to determine the most suitable definition of the date of the break. In many years, the date was the same based on 10 mm in 5 days or 25 mm in 14 days after April 1st. In the years when there was a discrepancy, the 25 mm in 14 days gave a better estimate of the rains required for broomrape to develop.

The 10 mm in 2 days prediction tends to over-predict early breaks and results in more false breaks. The 25 mm in 5 days tends to be over-conservative leaving many years without breaks. For these reasons, for the remainder of the analysis I use 25 mm in 14 days after April 1st to define the date of opening rains.

How often do early breaks occur?

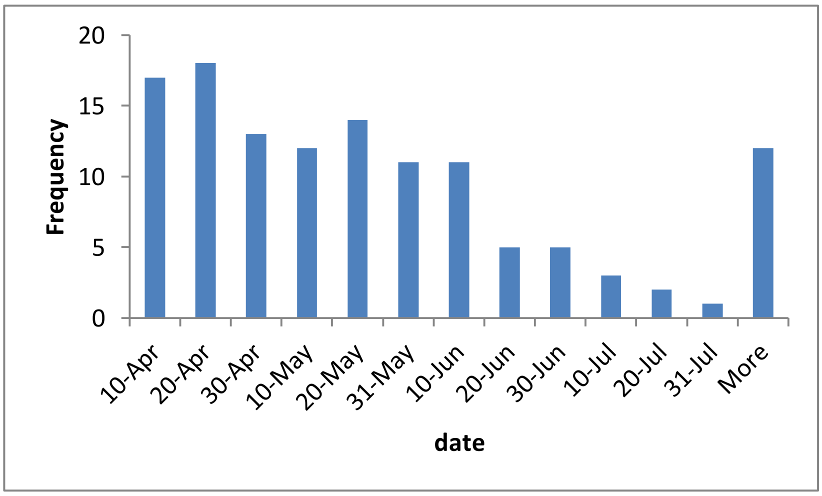

Figure 1. Histogram of the frequency of occurrence of dates of opening season rains

There is a reasonable spread of opening rains from the start of April until early June and opening season rainfall has usually occurred by then (Fig 1). The percentage of opening rains in each of the months April, May and June, coinciding with early, mid and late breaks respectively, is shown in Table 1. From Table 1, 39% of breaks occur in April and from Table 2, 31% of these do not have follow-up rains. Therefore a reliable opening break occurs in April in 27% of years.

What is the length of the growing season?

Huda *et al* define the end of the growing season as the date between September 1st and October 31st when less than 10 mm of rain was received after a 21 day period.

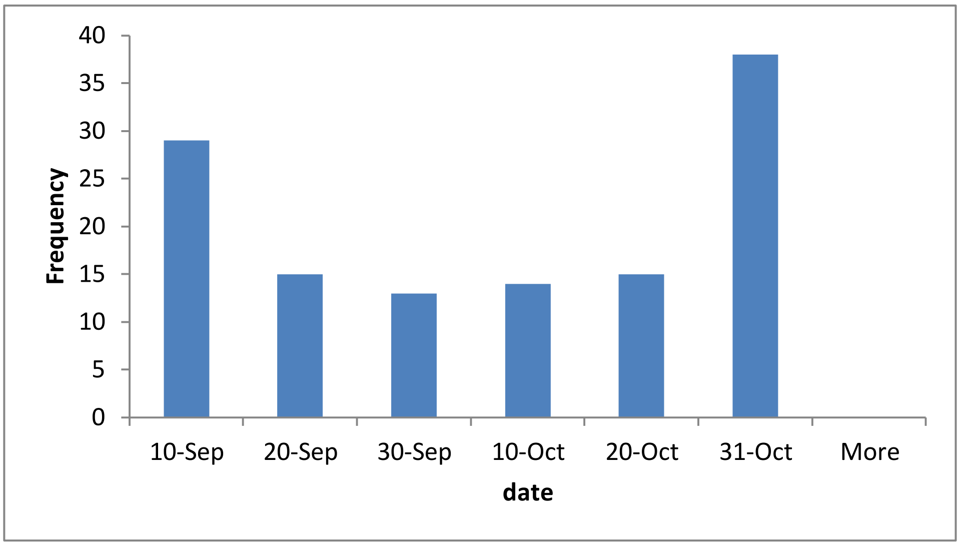

Figure 2. Histogram of the frequency of occurrence of dates for end of growing season

The histogram for the date of the end of the growing season shows that the growing season can persist to the end of October in many cases (31% of years) (Fig 2). In 21% of years there is no reliable rain after early September.

Huda *et al* made estimates of the reliability of growing season rainfall across several sites in southern South Australia. They calculated the number of weeks between May and October when at least 5 mm of rain was received in at least 50% of years (105 years of data). There were 19 weeks of reliable rain during that period in Murray Bridge. In comparison with other areas with low growing season rainfall in their report, this indicates relatively reliable rain. In other areas of the Quarantine Area rainfall is less reliable. Their analysis for Karoonda (76 years of data) gives 12 weeks of reliable rainfall.

At least in some parts of the quarantine area there will be reliable rain throughout the growing season and in three in ten years this will extend to the end of the growing season.

Broomrape development

Figure 3 shows the predicted dates for GDD for different opening rainfall dates. The grey shaded area is the period between the start of development and 500 GDD, when spraying would be too early. The yellow shaded area is between 500 and 1000 GDD, the useful spray period. The green line is 1500 GDD when emergence is predicted. In early breaks there is a relatively short period of time between the opening of the season and 500 GDD (the width of the shaded grey area) but a long period of time between 1000 GDD and 1500 GDD. This is reversed later in the growing season. Opportunities for spraying therefore occur soon after the start of the growing season when there is an early break. There is a greater time delay to the start of spraying later in the growing season but broomrape maturation occurs quicker in the warmer soils.

A broomrape plant that attaches at the end of July will have time to develop by the end of October, given suitable conditions (far right of Fig 3). Broomrape that develop at this time can be controlled by non-residual sprays at the end of August but this will be too late to control broomrape that attached in April, or the first few days of May as 1500 GDD will already be reached (as indicated by the arrows on Fig 3).

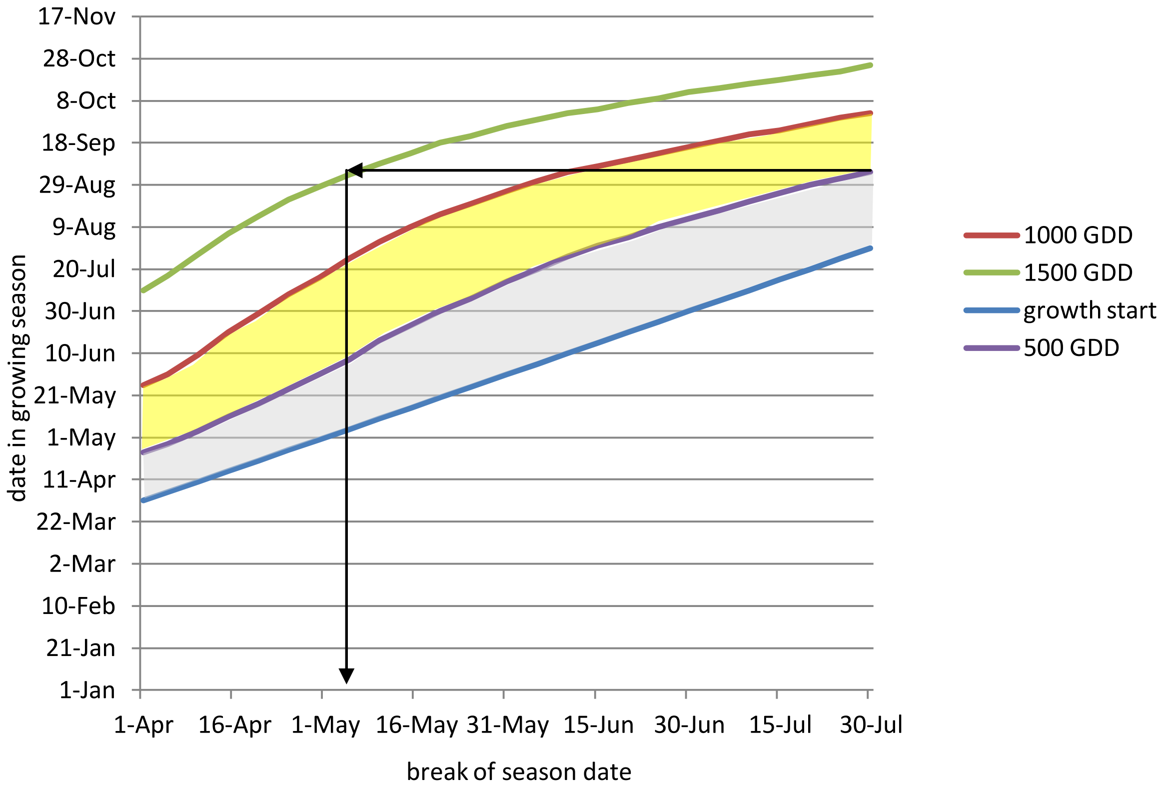

Figure 3. Progression of GDD with different starts to the opening of the growing season. See text for explanation.

How often will we need to spray twice?

Figure 3 shows that broomrape plants that germinate in late July are able to mature before the end of the growing season given adequate rainfall until the end of October. It would not be possible to adequately control these plants in addition to broomrape plants that germinated after opening rains in April with a single spray. This is provided that the early opening rains are followed up by further rains that sustain host growth.

If we define our requirement for a double spray as any time there are opening rains before April 30th with follow up rains, then we will be double spraying 27% of the time, or about two-three times in every ten years. This is based on Murray Bridge data – 39% of years had opening rain by May 7th but in 31% of cases there was no follow up rain (p =0.39 * (1-0.31).

Since 2000, there have been five breaks before May 7th (2000, 2006, 2007, 2009, 2010). In two of these years there were poor follow up rains (2006, 2009). This fits reasonably well with the prediction of 4 years with breaks before April 30th minus two years with poor follow up rains, leaving three years that would need double spraying.

In 48% of years where opening rains occurred by April 30th the growing season persisted into October and in 35% of years into late October. Spraying twice is therefore imperative in three to four years where there is a break before April 30th.

When should the second spray be applied?

From Figure 3 it can be seen that the first spray can be applied from the beginning of June although GDD monitoring will help define this. Broomrape plants that have germinated by April 30th will have passed 500 GDD by this date.

The second spray would need to be applied in late August to control broomrape plants attaching in late July, which do not reach 500 GDD until this date. Provided the herbicide has some residual effect, early-mid August applications may be effective.

Appendix

Data from Murray Bridge weather station used in calculations. Data missing for 1969. Opening rains are calculated from April 1st each year. In calculating false breaks only breaks occurring before June 30th were used.

Year	10 mm break	25 mm break 14 d	25 mm break 5 days	end growing season	Is 10mm in 2 days a false break? (0=no, 1=yes)	Is 25mm in 14 days a false break? (0=no, 1=yes)	Is 25mm in 5 days a false break? (0=no, 1=yes)
1886	23-Apr	24-Jul	24-Jul	12-Oct	1	na	na
1887	11-Apr	11-Apr	5-Nov	24-Oct	1	1	na
1888	3-May	5-May	5-May	15-Oct	0	0	0
1889	2-Apr	2-Apr	2-Apr	4-Oct	0	0	0
1890	16-May	23-May	12-Jun	26-Sep	0	0	0
1891	14-Apr	3-Oct	none	31-Oct	1	na	na
1892	17-Jun	9-Jul	9-Jul	31-Oct	0	na	na
1893	3-Apr	3-Apr	3-Apr	1-Sep	0	0	0
1894	19-Apr	19-Apr	19-Apr	1-Oct	1	1	1
1895	3-Apr	29-Apr	23-Jul	16-Sep	0	1	na
1896	4-Jun	4-Jun	28-Dec	8-Oct	0	0	na
1897	27-May	28-May	28-May	27-Sep	0	0	0
1898	4-Apr	4-Apr	14-Jun	20-Sep	0	0	0
1899	3-Apr	9-Jun	8-Aug	1-Sep	0	0	na
1900	16-Apr	16-Apr	18-May	17-Oct	0	0	0
1901	3-Apr	31-May	18-Jun	31-Oct	1	0	0
1902	16-Jun	16-Jun	19-Jun	8-Oct	1	1	1
1903	5-Apr	18-Apr	7-Jun	31-Oct	0	0	0
1904	18-Apr	13-Jun	1-Jul	20-Sep	0	0	na
1905	5-Apr	24-Apr	24-Apr	13-Oct	0	0	0
1906	4-Jun	7-Jun	7-Jun	25-Oct	0	0	0
1907	5-Apr	18-Apr	21-May	1-Sep	1	1	0
1908	15-Apr	14-May	15-May	31-Oct	1	1	1
1909	19-Apr	20-Apr	15-May	25-Oct	0	0	0
1910	26-May	26-May	26-May	31-Oct	0	0	0
1911	10-May	18-May	2-Sep	1-Sep	0	0	na
1912	10-Jun	24-Jun	25-Jun	25-Oct	0	0	0
1913	21-Apr	21-Apr	21-Apr	10-Sep	1	1	1
1914	25-Nov	25-Nov	25-Nov	1-Sep	na	na	na
1915	10-Apr	14-Apr	15-May	15-Oct	1	1	0
1916	31-May	3-Jun	3-Jun	10-Sep	0	0	0
1917	6-Apr	13-May	8-Sep	31-Oct	1	0	na
1918	10-May	19-May	7-Oct	25-Sep	0	1	na
1919	23-May	8-Sep	27-Dec	5-Oct	0	na	na
1920	1-Jun	3-Jun	3-Jun	31-Oct	0	0	0
1921	23-May	29-May	31-May	11-Oct	0	0	0
1922	25-Apr	2-May	3-May	6-Sep	0	0	0
1923	8-May	9-May	9-May	13-Sep	0	0	0
1924	20-May	20-May	20-May	31-Oct	0	0	0
1925	6-Apr	6-Apr	8-Apr	19-Oct	0	0	0
1926	25-Apr	1-May	29-Sep	31-Oct	0	1	na
1927	26-May	4-Aug	1-Nov	22-Sep	1	na	na
1928	25-May	25-May	3-Oct	26-Sep	0	0	na
1929	1-Sep	27-Dec	27-Dec	20-Oct	na	na	na
1930	29-Jun	2-Jul	2-Jul	30-Sep	0	na	na
1931	15-May	10-Oct	none	25-Sep	0	na	na

Year	10 mm break	25 mm break 14 d	25 mm break 5 days	end growing season	Is 10mm in 2 days a false break? (0=no, 1=yes)	Is 25mm in 14 days a false break? (0=no, 1=yes)	Is 25mm in 5 days a false break? (0=no, 1=yes)
1932	18-Apr	1-Jun	12-Jun	31-Oct	0	0	0
1933	26-May	29-May	29-May	8-Oct	0	0	0
1934	4-Jun	14-Aug	15-Aug	31-Oct	1	na	na
1935	13-Apr	15-Apr	16-Sep	1-Sep	0	0	na
1936	7-Apr	8-Apr	8-Apr	20-Sep	1	1	1
1937	31-May	3-Jun	1-Dec	15-Sep	0	0	na
1938	16-Apr	17-Apr	17-Apr	15-Sep	0	0	0
1939	6-Apr	9-Apr	9-Apr	20-Sep	1	1	1
1940	24-Apr	25-Apr	20-Dec	1-Sep	0	0	na
1941	3-Apr	3-Apr	9-Jun	31-Oct	0	0	1
1942	27-Apr	27-Apr	27-Apr	14-Oct	0	0	0
1943	2-Aug	8-Aug	18-Dec	31-Oct	na	na	na
1944	3-May	5-May	none	1-Sep	1	1	na
1945	4-May	8-May	8-May	12-Oct	0	0	0
1946	17-May	18-May	18-May	21-Sep	0	0	0
1947	11-Apr	16-Jul	3-Sep	24-Sep	1	na	na
1948	12-Apr	12-Apr	12-Apr	14-Sep	0	0	0
1949	6-May	6-May	6-May	9-Sep	0	0	0
1950	30-May	31-May	none	11-Sep	0	0	na
1951	12-Apr	17-Apr	14-May	17-Sep	0	0	0
1952	17-Apr	17-Apr	27-Oct	22-Oct	0	0	na
1953	20-Jun	20-Jun	21-Oct	23-Sep	0	0	na
1954	6-Apr	14-Apr	14-Apr	1-Sep	0	0	0
1955	12-Apr	12-Apr	12-Apr	15-Sep	0	0	0
1956	11-May	16-May	18-Oct	31-Oct	0	0	na
1957	21-Jun	16-Sep	19-Sep	4-Sep	1	na	na
1958	14-Apr	14-May	15-May	31-Oct	1	0	0
1959	1-Apr	1-Apr	1-Apr	2-Sep	*1*	*1*	*1*
1960	21-Apr	26-Apr	5-May	2-Sep	0	0	0
1961	7-Apr	7-Apr	7-Apr	26-Sep	0	0	0
1962	1-May	4-Jun	20-Oct	12-Sep	0	1	na
1963	26-Apr	27-Apr	27-Apr	8-Oct	0	0	0
1964	8-Apr	8-Apr	8-Apr	31-Oct	1	1	1
1965	8-May	22-Jun	22-Jun	7-Oct	0	1	1
1966	4-May	6-May	2-Dec	8-Sep	1	1	na
1967	13-Aug	14-Aug	none	8-Sep	na	na	na
1968	29-Apr	29-Apr	29-Apr	2-Sep	0	0	0
1970	22-Apr	29-Aug	27-Sep	20-Oct	0	na	na
1971	26-Apr	26-Apr	27-Apr	23-Oct	0	0	0
1972	9-Apr	8-Jul	none	4-Sep	0	na	na
1973	18-Apr	25-Apr	27-Aug	31-Oct	0	0	na
1974	6-Apr	1-Apr	11-Apr	31-Oct	0	0	0
1975	25-May	1-Apr	24-Oct	31-Oct	1	0	na
1976	21-Sep	13-Aug	21-Sep	31-Oct	na	na	na
1977	8-Apr	31-May	28-Nov	6-Oct	1	0	na
1978	10-Apr	11-Apr	11-May	9-Sep	1	1	0
1979	26-May	30-May	28-Aug	31-Oct	1	1	na
1980	18-Apr	18-Apr	18-Apr	1-Sep	0	0	0
1981	1-Jun	1-Jun	none	18-Sep	0	0	na
1982	27-Apr	27-Apr	29-Apr	1-Sep	1	1	0
1983	9-Apr	10-Apr	10-Apr	30-Sep	0	0	0
1984	3-Jul	6-Apr	25-Jul	24-Oct	na	0	na
1985	5-Apr	14-Apr	18-Apr	18-Oct	1	1	1
1986	17-Apr	16-May	15-Aug	10-Oct	0	0	na
1987	28-Apr	2-May	2-May	19-Sep	0	0	0

Year	10 mm break	25 mm break 14 d	25 mm break 5 days	end growing season	Is 10mm in 2 days a false break? (0=no, 1=yes)	Is 25mm in 14 days a false break? (0=no, 1=yes)	Is 25mm in 5 days a false break? (0=no, 1=yes)
1988	16-May	17-May	24-May	8-Oct	0	0	0
1989	7-May	7-May	9-May	31-Oct	0	0	0
1990	21-Apr	25-Jun	27-Jun	16-Oct	1	0	0
1991	25-Apr	4-Jun	5-Jun	8-Oct	1	0	0
1992	6-Apr	14-May	14-May	31-Oct	0	0	0
1993	8-Jul	21-Jun	8-Jul	31-Oct	na	0	na
1994	6-Jun	7-Jun	7-Jun	1-Sep	0	0	0
1995	30-Apr	8-Apr	3-May	1-Sep	0	1	1
1996	18-Jun	26-Jun	27-Aug	31-Oct	0	0	na
1997	3-May	7-May	2-Sep	10-Oct	0	0	na
1998	12-Apr	20-Apr	20-Apr	30-Oct	0	0	0
1999	14-Jun	20-Jul	3-Oct	1-Sep	0	na	na
2000	10-Apr	1-Apr	12-Apr	30-Sep	0	0	0
2001	8-Apr	28-May	12-Sep	31-Oct	1	0	na
2002	19-May	19-May	20-May	20-Oct	0	0	0
2003	1-May	13-May	24-Aug	23-Oct	0	0	na
2004	15-Jun	15-Jun	5-Aug	4-Sep	0	0	na
2005	11-Jun	11-Jun	11-Jun	31-Oct	0	0	0
2006	28-Apr	7-May	none	1-Sep	0	1	na
2007	27-Apr	27-Apr	27-Apr	1-Sep	0	0	0
2008	17-May	18-May	18-May	14-Oct	0	0	0
2009	25-Apr	26-Apr	26-Apr	31-Oct	1	1	0
2010	6-Apr	9-Apr	29-May	31-Oct	0	0	0