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Postemergence Small Broomrape (*Orobanche minor*) Control in Red Clover[1]

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Abstract: Small broomrape is an annual, parasitic weed that was discovered recently in Oregon's red clover seed production system. Field experiments were conducted in 2002 and 2003 at two locations to evaluate 10 herbicide treatments applied after small broomrape emergence in red clover. Bentazon, bromoxynil, glyphosate, imazamox, imazamox plus bentazon, imazethapyr, MCPA, and pendimethalin were evaluated. Small broomrape density, small broomrape seed viability after treatment, and clover injury and seed yield were quantified. Small broomrape control with imazamox, glyphosate, and imazamox plus bentazon treatments was greater than the nontreated check in both years. However, imazamox and imazamox plus bentazon treatments were the only herbicide treatments that consistently exhibited a high level of crop safety, reduced small broomrape density, and did not reduce red clover yield. Herbicide treatments did not prevent production of viable small broomrape seeds. Future research is needed to develop control options that will prevent red clover yield loss and viable small broomrape seed production when applied before small broomrape emergence.

Nomenclature: Bentazon; bromoxynil; glyphosate; imazamox; imazethapyr; MCPA; pendimethalin; small broomrape, *Orobanche minor* Sm. #[3] ORAMI; red clover, *Trifolium pratense* L. # TRFRE.
Additional index words: Parasitic weed.
Abbreviations: DAT, days after treatment.

INTRODUCTION

Holoparasitic angiosperms of the genus *Orobanche* (the broomrapes) have long been problematic weeds in the regions surrounding the Mediterranean (Pieterse 1979). Damage to crops by *Orobanche* spp. is common in these warm and dry areas (ter Borg 1986) with yield loss ranging from zero to complete crop failure, depending on the level of infestation (Barker et al. 1996; Foy et al. 1989; Manschadi et al. 1996). *Orobanche* spp. cause damage by drawing nutrients and water from host plants through root attachment (Baccarini and Melandri 1967; Parker and Riches 1993; Saghir et al. 1973).

Small broomrape is a parasite of red clover and several other crop and weed species. Small broomrape is a prolific seed producer with fecundity of over 1,000,000 seeds/plant (Pieterse 1979). Dustlike small broomrape seeds can be spread by wind, water, machinery, contaminated crop seed, animals, and clothing. Seed may remain dormant in the soil for long periods of time until induced to germinate by host exudates (ter Borg 1986).

In Oregon, small broomrape germination and attachment occurs in red clover from January to February. The parasite then stays beneath the soil surface for approximately 4 to 5 mo while drawing nutrients and water from its host. Small broomrape emerges and flowers from June to July, producing viable seed within 3 wk after stalk emergence. Viable seed can be produced even after flowering plants have been hand-pulled.

Seed contamination, reduction in seed yield, and host plant death may be consequences of small broomrape infestation. There were six reported infestations of small broomrape from 1923 to 1997 in Oregon. However, in 1998, after identification in a single red clover seed production field, the number of reported infestations increased to 15 in 2000 and 22 in 2001 (J. B. Colquhoun, unpublished data). Small broomrape is listed as a federal noxious weed and may be prohibited as a seed contaminant by many of Oregon's trading partners, potentially eliminating Oregon red clover seed export.

To date, small broomrape control options are limited and there are no registered herbicides that control small broomrape in red clover. In addition, growers are often unaware of an infestation until small broomrape shoots emerge. Recent research has shown that *Orobanche* spp.

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

can be controlled in various crops with glyphosate, sulfonylurea, and imidazolinone herbicides (Aly et al. 2001; Garcia-Torres et al. 1987; Hershenhorn et al. 1998; Kleifeld et al. 1998). However, herbicides have not been evaluated for postemergence control of small broomrape in red clover seed production. Control options for emerged small broomrape are needed as ‘‘rescue treatments,’’ given the rapid spread to previously uninfested fields in recent years. Therefore, our objectives were to evaluate several postemergence herbicide treatments for crop safety, crop yield, control of small broomrape, and effect on small broomrape seed viability in red clover production systems in western Oregon.

MATERIALS AND METHODS

Studies were conducted in small broomrape–infested red clover seed production fields in Washington and Clackamas counties, OR, in 2002 and 2003, respectively. Before planting, fields were disked and harrowed to prepare a suitable seed bed. ‘Kenland’ medium red clover was planted into a Hillsboro loam soil (fine-silty, mixed, mesic Ultic Argixerolls) at the Washington county location in October 2000 and into a Quantama loam soil (fine-loamy, mixed, mesic Aquultic Haploxerolls) at the Clackamas county location in October 2001. Red clover fields were managed with common grower practices consisting of a forage harvest in the first year of production, and herbicide plots were established in the second year of red clover production. The experimental design was a randomized complete block with four replications and plot size was 2.4 by 9.1 m.

Herbicides tested were bentazon at 1,120 g ae/ha, bromoxynil at 280 g ai/ha, glyphosate at 26, 53, and 105 g ae/ha, imazamox at 45 g ae/ha, imazamox and bentazon at 45 g ae/ha and 1,120 g ae/ha, respectively, imazethapyr at 105 g ae/ha, MCPA at 680 g ae/ha, and pendimethalin at 2,780 g ai/ha. Herbicides were chosen on the basis of demonstrated *Orobanche* spp. efficacy (Goldwasser et al. 2003; Qasem 1998) or registration for use on *Fabaceae* spp. crops in Oregon or elsewhere (or both). All bentazon, bromoxynil, glyphosate, imazamox, imazethapyr, and MCPA treatments were applied with nonionic surfactant at 0.25% (v/v). A nontreated check treatment was included in both experiments. Treatments were broadcast with a bicycle wheel sprayer calibrated to deliver a solution volume of 187 L/ha. Application dates were June 20, 2002, for the Washington county site and May 29, 2003, for the Clackamas county site and coincided with small broomrape emergence. The 2003 application date occurred earlier in the calendar year because of more rapid accumulation of growing degree days and, thus, greater small broomrape development and an earlier emergence date (Eizenberg et al. 2005). Red clover was at the four-trifoliate growth stage at the time of application in both years.

Small broomrape stalk number per square meter was counted at herbicide application to quantify the density of emerged plants that were treated. Small broomrape density was quantified 10 and 20 d after treatment (DAT). Small broomrape distribution was variable across experimental sites. Therefore, small broomrape survival and emergence after treatment was assessed as a percent of the pretreatment small broomrape density. Treatments that reduced pretreatment density below 100% were considered to have postemergence activity on small broomrape.

Red clover herbicide injury was evaluated visually 10 and 20 DAT on a scale of 0 to 100% injury; with 100% injury equal to crop death. Small broomrape injury to red clover did not cause symptoms resembling herbicide injury. Red clover seed yield was quantified from hand-harvested 1-m^2 quadrats in each plot on September 5, 2002, and September 4, 2003.

In a related small broomrape seed viability study, five randomly selected, mature small broomrape plants with dry seed capsules were harvested from each plot of the field experiments on August 9, 2002, and August 13, 2003. On August 16, 2002, and September 10, 2003, the five small broomrape stalks taken from each field plot were mixed with potting media[4] in individual 600-cm^2 pots and one Kenland red clover plant was planted in each pot. Pots were placed in a greenhouse where temperature was approximately 22 C and lights provided 12 h of light per day. The experimental design was a randomized complete block with four replications. Red clover plants were clipped once before initial flowering to simulate a forage harvest practiced commonly by growers. Experiments were harvested at red clover full bloom on December 18, 2002, and January 5, 2004. The number of small broomrape attachments per red clover plant was quantified. Small broomrape seed viability was tested with host plants due the low efficacy of artificial germination stimulants, such as GR24 (R. D. Lins, unpublished data), and to mimic field germination conditions.

ANOVA was used for all experiments, and treatment means were separated using Fisher’s protected LSD test ($P = 0.05$). Data were analyzed with PROC GLM and PROC TTEST using SAS.[5] Red clover injury and small

[4] Sunshine Mix #1 potting mix, Sun Gro Horticulture Inc., 110th Avenue NE, Suite 490, Bellevue, WA 98008.

[5] SAS Institute Inc., 1996, Box 8000, SAS Circle, Cary, NC 25711-8000.

Table 1. Visual estimate of red clover injury, small broomrape density, and red clover seed yield after herbicide application.

Treatment[a]	Rate	Red clover injury				Small broomrape density[b]				Red clover seed yield	
		2002		2003		2002		2003			
		10 DAT[c]	20 DAT	10 DAT	20 DAT	10 DAT	20 DAT	10 DAT	20 DAT	2002	2003
	g ae or ai/ha[d]	%				% of initial density				kg/ha	
Nontreated check	—	0	0	0	0	130	139	183	264	252	78
Bentazon	1,120	0	0	3	5	130	140	228	369	323	47
Bromoxynil	280	3	5	11	19	137	104	121	227	330	61
Glyphosate	26	3	3	8	10	116	104	52	61	280	100
Glyphosate	53	0	14	5	18	110	94	102	80	189	49
Glyphosate	105	10	24	20	14	106	84	160	26	53	60
Imazamox	45	3	3	13	16	93	42	114	77	285	95
Imazamox + bentazon	45 + 1,120	0	0	0	3	89	52	100	25	272	73
Imazethapyr	105	15	24	8	14	88	37	148	174	172	66
MCPA	680	18	20	26	38	172	155	153	163	344	73
Pendimethalin	2,780	5	3	15	20	132	98	183	236	336	57
LSD (0.05)		3	3	12	20	18	24	48	62	135	NS

[a] All treatments except pendimethalin were applied with nonionic surfactant at 0.25% (v/v).

[b] Values greater than 100 indicate that emerged small broomrape was not controlled and additional flowering stalks emerged after herbicide treatment. Values less than 100 indicate that small broomrape density at time of application was reduced by postemergence activity of the herbicide treatment.

[c] Abbreviations: DAT, days after treatment on June 20 and May 29, for 2002 and 2003, respectively; NS, not significant.

[d] Bentazon, glyphosate, imazamox, imazethapyr, and MCPA are expressed as g ae/ha.

broomrape density data were analyzed as percentages. Red clover yield per year was compared using a Student's *t* test.

RESULTS AND DISCUSSION

Red Clover Injury. Red clover injury was generally greater and more variable in 2003 than 2002 (Table 1). In 2002, MCPA and imazethapyr caused the most injury at 10 DAT, whereas glyphosate at 105 g ae/ha and imazethapyr had the highest injury ratings 20 DAT.

In 2003, injury at 10 DAT was greatest where MCPA, glyphosate at 105 g/ha, or pendimethalin were applied, but at 20 DAT, bromoxynil, glyphosate at 53 g/ha, MCPA, and pendimethalin treatments caused the greatest injury. However, only the MCPA treatment differed from the check at 20 DAT because of the highly variable response in 2003. In both years, red clover injury was lower when bentazon, glyphosate at 26 g/ha, imazamox, and imazamox plus bentazon were applied to control small broomrape. The addition of bentazon to imazamox minimized red clover injury when compared with imazamox applied alone. This response is consistent with bentazon antagonism of imazamox reported in other studies (Zollinger and Fitterer 1998).

Red clover seed yield differed between years (*t*-test; $P < 0.001$). The 2002 seed yield varied among treatments and was greater, on an average, than the 2003 seed yield. In 2002, seed yield was lower with glyphosate at 105 g/ha and imazethapyr than where bentazon, bromoxynil, MCPA, and pendimethalin were applied. In 2003, herbicide treatment did not affect red clover yield. Red clover seed production was less in 2003 compared with 2002, presumably because of differences in small broomrape density and available moisture between years. Before herbicide application, mean small broomrape density across each experiment was 14.4 plants/m^2 in 2002 and 29.5 plants/m^2 in 2003.

Small Broomrape Control. Herbicide effects on small broomrape density differed between years (Table 1). In 2002, none of the treatments reduced small broomrape density at 10 DAT compared with small broomrape density before herbicide application. By 20 DAT, the imazamox, imazamox plus bentazon, and imazethapyr treatments reduced pretreatment small broomrape densities by as much as 63%. Similarly, in 2003, herbicides did not decrease small broomrape density 10 DAT compared with pretreatment density. Only the high rate of glyphosate and imazamox plus bentazon treatments reduced pretreatment densities at 20 DAT; however, these treatments did not differ significantly from the imazamox or the other glyphosate treatments.

Plots treated with MCPA at 10 DAT in 2002 and bentazon at 20 DAT in 2003 had greater small broomrape densities than the nontreated check. These herbicides do not appear to have activity on small broomrape. However, red clover plants damaged by these herbicides may have triggered an increase in small broomrape plant density. Small broomrape emergence appears to increase when red clover is injured or wounded (R. D. Lins, unpublished data). This response may be because of eth-

Table 2. Parasitism of red clover plants by small broomrape seed produced from herbicide-treated plants.[a]

Treatment[b]	Rate	Small broomrape parasitism 2002	Small broomrape parasitism 2003
		Attachments/clover plant	
	g ae or ai/ha[c]		
Nontreated	—	3.8	1.8
Bentazon	1,120	5.3	5.3
Bromoxynil	280	4.5	4.0
Glyphosate	26	2.3	0.8
Glyphosate	53	2.8	2.5
Glyphosate	105	0.3	1.0
Imazamox	45	0.3	8.3
Imazamox + bentazon	45 + 1,120	1.3	6.3
Imazethapyr	105	0.3	2.8
MCPA	680	1.0	9.0
Pendimethalin	2,780	1.5	4.3
LSD (0.05)		3.6	NS

[a] Abbreviation: NS, not significant.

[b] Treatments applied to red clover in the field from which small broomrape seed stalks were harvested and seed viability tested. All treatments except pendimethalin were applied with nonionic surfactant at 0.25% (v/v).

[c] Bentazon, glyphosate, imazamox, imazethapyr, and MCPA are expressed as g ae/ha.

ylene production, which Zehhar et al. (2002) have shown to be capable of inducing germination in branched broomrape (*O. ramosa* L.).

Small Broomrape Seed Viability. In the small broomrape seed viability study, the effect of herbicide treatment on small broomrape attachment per red clover plant differed in 2002 but not in 2003 (Table 2). However, although treatments differed in 2002, no herbicide reduced the number of small broomrape attachments per red clover plant as compared with the nontreated check. Therefore, herbicide treatment effects may be insignificant, given the copious seed production of small broomrape.

Implications for Small Broomrape Management. This study demonstrated that small broomrape emergence and density in red clover can be reduced through the use of postemergence herbicide treatments. However, in this study, imazamox and imazamox plus bentazon were the only herbicide treatments that consistently exhibited a high level of crop safety, reduced small broomrape density, and did not reduce red clover yield. Glyphosate at 105 g/ha also controlled small broomrape, but crop safety and subsequent crop yield were poor. Although these herbicides reduced small broomrape density, seed production and viability of seed from treated plants were not eliminated. Given the ability of small broomrape to produce large amounts of seed, the weed seed bank will likely increase even when herbicides are applied. With this in mind, integrated management of small broomrape must include an approach to reduce emergence of small broomrape shoots and subsequent contributions to soil seed banks. Strategies such as rotation or intercropping with small broomrape false host crops are recommended for an integrated small broomrape control program (Ross et al. 2004).

Herbicides were evaluated with the intention that they could serve as rescue treatments for emerged small broomrape populations in the growing season in which they are discovered in red clover production fields. Preliminary results of subsequent research suggest that imazamox applied before small broomrape emergence prevented both emergence and small broomrape seed production. Given that small broomrape is a holoparasite that uses water and nutrient resources that would otherwise be available to red clover, early management is critical to red clover seed yield. Further research has been conducted to develop a predictive temperature-based model for imazamox application after small broomrape attachment but before emergence (Eizenberg et al. 2005). The use of this model will require frequent field inspections or knowledge of infested fields for proper herbicide application timing.

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