Abstract. 2011 Report – Weed Research in Mint

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Statement of purpose. This research develops new knowledge on weed control methods in peppermint and spearmint, including information on the selectivity and efficacy of new herbicides and how to integrate these herbicides into weed management programs for mint. The research also characterized weed resistance to commonly used herbicides in mint production.

Summary of objectives.

1. Identify and evaluate new herbicides for use in mint crops including dormant herbicide applications and broadleaf weed control in double cut mint.
2. Determine the extent of herbicide resistant weeds in mint and determine their response to mint herbicides.

Actions taken.

1. A field trial was conducted to determine response of peppermint to ten preemergence applied herbicides. A second field trial was conducted in peppermint to determine response of pigweed and mint to herbicides applied soon after the first cutting. A third field trial was conducted to determine the efficacy of several herbicide treatments for white cockle control.
2. Response of nine weed species and biotypes to mint herbicides were tested. Herbicide dose response studies were conducted on resistant weed biotypes. Response of resistant weed biotypes to herbicides with different mode of action that are labeled in mint was determined.

Results.

1. Pyroxasulfone, saflufenacil, and sulfentrazone plus carfentrazone caused only minor injury when applied to dormant peppermint. Indaziflam injured mint and reduced stand and oil yield. Weed control varied among herbicides. Sulfentrazone controlled redroot pigweed in the regrowth of double cut mint when applied after the first harvest and did not injure mint, whereas pyroxasulfone controlled pigweed, but injured mint when applied after the first harvest. Saflufenacil and clomazone controlled white cockle well in peppermint when applied in the fall with paraquat. Clomazone plus paraquat or terbacil plus paraquat applied in March also reduced white cockle numbers regardless of the fall treatment.
2. Nine of 22 pigweed biotypes collected from mint fields were resistant to terbacil and were cross resistant to metribuzin. Pigweed resistant biotypes were 3.4 to 17 fold resistant compared to a susceptible biotype. All terbacil resistant pigweed biotypes were susceptible to bromoxynil and bentazon. All biotypes of four grass species collected were not resistant to clethodim or sethoxydim. A horseweed biotype showed resistance to paraquat.

2011 Final Report - Weed Research in Mint

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1. Identify and evaluate new herbicides for use in mint crops including dormant herbicide applications and broadleaf weed control in double cut mint.

Three field trials evaluated several new herbicides in peppermint.

Trial 1. A trial was conducted to evaluate eleven herbicide treatments applied to dormant peppermint at WSU-IAREC near Prosser, WA. Herbicides were applied March 3, 2011 with a bike CO_2 sprayer and treatments were arranged in a randomized complete block design and replicated 4 times in 10 by 20 foot plots. Treatments included KIH-485 (pyroxasulfone) at 0.19 lb ai/a, a premix of pyroxasulfone and flumioxazin (Chateau) called Fierce, flumioxazin alone at 0.125 lb ai/a, indaziflam (Alion) at 0.044 and 0.065 lb ai/a, Sharpen (saflufenacil) at 0.066 lb ai/a plus Prowl (pendimethalin), Spartan Charge (sulfentrazone plus carfentrazone) at 7.7 fl oz/a, Spartan 4F (sulfentrazone) at 0.19 lb ai/a, sulfentrazone plus Command (clomazone) at 0.19 + 0.35 lb ai/a, and Sinbar (terbacil) at 0.5 lb ai/a (Table 1).

Weed control and peppermint injury were rated at various times through April and May. The primary weeds present were tall hedge mustard, kochia, common lambsquarters, with sparse amounts of Russian thistle, common groundsel, and barnyardgrass. Peppermint was harvested July 26, 2011 with a sickle bar mower (40 inch swath) and hay was weighed. A 21 lb subsample of fresh hay from each plot was removed and dried and oil was steam distilled.

Saflufenacil (Sharpen/Kixor) 0.066 lb ai/a + Prowl H_2O 2 pt/a. Saflufenacil controlled lambsquarters well, suppressed kochia, but did not control tall hedge mustard (Tables 2 and 3). Peppermint was not significantly injured (7%) by dormant application of saflufenacil plus Prowl in 2011 (Table 1). Mint tolerance to saflufenacil was inconsistent in a 2010 study, but only minor injury was observed in 2009 studies. Saflufenacil tank mixed with Prowl H2O has the potential to improve grass control and common lambsquarters control. Saflufenacil controlled white campion (white cockle) well in a greenhouse study and one field study near Post Falls, ID in 2011. Peppermint treated with saflufenacil plus Prowl H2O yielded slightly lower hay yield (13 ton/acre) than several other herbicide treatments, but statistically similar to hay yield of the nontreated weedy checks or standard Sinbar treatment (Table 3). Oil yield was not statistically different from the highest yielding treatments and averaged 67 lbs/acre.

Pyroxasulfone (KIH-485) 0.19 lb ai/a. Pyroxasulfone only slightly suppressed tall hedge mustard but controlled common lambsquarters and kochia well (Tables 2 and 3). Tall hedge mustard control with pyroxasulfone was marginal, but when combined with terbacil was excellent (Table 2). Dormant applications of pyroxasulfone alone or with terbacil only caused minor on peppermint (Table 1). Pyroxasulfone was a good tank mix partner with terbacil (Sinbar) as it controls kochia, annual grasses, and common groundsel preemergence that Sinbar frequently misses. Plots treated with pyroxasulfone or pyroxasulfone plus terbacil yielded equal to the highest hay and oil yields in the trial, averaging 15.1 to 15.2 ton hay/acre and 68 to 72 lbs oil/acre, respectively (Table 3).

Fierce (premix of Chateau and pyroxasulfone). Fierce only suppressed tall hedge mustard, but controlled kochia, common groundsel, common lambsquarters and most weeds present in the 2011 study (Tables 2 and 3). Dormant applications of Fierce resulted in little or no peppermint injury (Table 1). Pyroxasulfone controls annual grass weeds that Chateau is typically weak on making this a good premix. Peppermint treated with Fierce averaged 13.7 ton hay/acre similar to highest yields in the trial and averaged 62.1 lbs oil/acre, slightly lower than the highest yielding treatments, but similar to the standard terbacil treatment (Table 3).

Spartan Charge 7.7 fl oz/a. This premix contains carfentrazone (a.i. in Aim) and sulfentrazone (a.i. in Spartan). No Gramoxone was added as carfentrazone is a contact burn-down herbicide. Spartan Charge did not control mustards well and this premix typically misses grass weeds compared to paraquat (Gramoxone) in other tests conducted in alfalfa. Spartan Charge controlled common lambsquarters and kochia well (Tables 2 and 3). Spartan Charge caused some minor mint injury in April (7%) which soon dissipated (Table 1). Peppermint treated with Spartan Charge yielded 14.7 ton hay/acre and 79.2 lbs oil/acre, which was greater than the standard terbacil treatment (Table 3).

Indaziflam (Alion) 0.044 and 0.065 lb ai/a. Indaziflam is a new herbicide labeled for use in turf, trees, and vine crops under the trade name Alion. Indaziflam controls many annual grass weeds and common lambsquarters. Indaziflam did not control kochia and tall hedge mustard well (Tables 2 and 3). Mint lacked good tolerance to indaziflam in 2009, but had good tolerance in 2010 trials. In 2011, we observed significant peppermint injury and reduced stands from dormant applied indaziflam at both rates, so we will discontinue looking at this compound due to lack of mint safety (Table 1). Peppermint hay and oil yields from indaziflam treated plots averaged the lowest in the trial and mint was stunted season long (Table 3).

Flumioxazin (Chateau) 4 oz/a. Flumioxazin controlled kochia, common lambsquarters, and common groundsel well and suppressed tall hedge mustard (Table 2). Flumioxazin control of Russian thistle and annual grasses was not adequate (data not shown). Flumioxazin premixed with pyroxasulfone (Fierce) controlled all weeds in the study (see above section on Fierce). Only minor peppermint injury was observed following dormant applications of flumioxazin (Table 1). Flumioxazin treated plots averaged 15.4 ton hay/acre and 73.3 lb oil/acre, similar to greatest yielding treatments (Table 3).

Sulfentrazone (Spartan 4F) 6 fl oz/a. Sulfentrazone controlled kochia and common lambsquarters well, but was weak on tumble and tall hedge mustard, and annual grasses (Tables 2 and 3). When tank mixed with Command the combination provided good control of all weeds in the study (see Command section below). Sulfentrazone did not injure peppermint and hay and oil yields (14 ton/acre and 64.1 lbs/acre, respectively) were statistically similar to the highest yielding treatments (Table 3).

Clomazone (Command) at 0.35 lb ai/a with Spartan. Clomazone caused typical bleaching injury on peppermint for several weeks after emergence, (averaged 14 %) and early May (<10%), but no injury was evident by early June (Table 1). Clomazone tanked mix with sulfentrazone provided good control of mustard, kochia, and common groundsel (Tables 2 and 3). Peppermint hay and oil yield averaged 15.4 ton/acre and 71.2 lb/acre, respectively and were similar to greatest yielding treatments in the trial (Table 3).

Terbacil (Sinbar) 0.5 lb ai/a. Terbacil provided the good control of tall hedge mustard, but was poor on kochia and common groundsel (Tables 2 and 3). Terbacil could be tank mixed with Chateau, Spartan, or pyroxasulfone (not labeled) to pick up these additional weeds that it misses. Peppermint hay yields were similar to the weedy check, possibly reflecting the poor control of several weeds that terbacil missed in this trial (Table 3).

Pyroxasulfone, saflufenacil, Fierce, and Spartan Charge all controlled selected weeds well and resulted in minimal injury to peppermint when applied to dormant mint in early March. These herbicides are currently not labeled in mint and will continue to be evaluated in future trials.

Table 1. Peppermint injury following eleven dormant applied herbicide treatments near Prosser, WA in 2011.

Crop Description Rating Date				Peppermint Injury Apr-19-2011		Peppermint Injury May-6-2011		Peppermint Injury May-26-2011	
Trt	Treatment	Rate	Unit	%		%		%	
1	Nontreated			0	d	0	d	0	c
2	Sulfentrazone (Spartan) Gramoxone Inteon	0.19 0.5	lb ai/a lb ai/a	0	d	0	d	0	c
3	Pyroxasulfone (KIH485) Gramoxone Inteon	0.19 0.5	lb ai/a lb ai/a	1	cd	0	d	0	c
4	Pyroxasulfone (KIH485) Terbacil (Sinbar) Gramoxone Inteon	0.19 0.38 0.5	lb ai/a lb ai/a lb ai/a	4	cd	0	d	0	c
5	Sulfentrazone (Spartan) Clomazone (Command) Gramoxone Inteon	0.19 0.35 0.5	lb ai/a lb ai/a lb ai/a	14	b	9	c	1	c
6	SulfentrazoneCarfent (SpartanCharge)	0.21	lb ai/a	7	bcd	1	d	0	c
7	Flumioxazin (Chateau) Gramoxone Inteon	0.128 0.5	lb ai/a lb ai/a	5	bcd	0	d	0	c
8	Terbacil (Sinbar) Gramoxone Inteon	0.5 0.5	lb ai/a lb ai/a	5	bcd	0	d	0	c
9	Flumioxazin Pyroxasulfone (Fierce) Gramoxone Inteon	0.144 0.5	lb ai/a lb ai/a	3	cd	0	d	0	c
10	Saflufenacil (Sharpen) Pendimethalin (Prowl) (MSO)	0.066 1 1	lb ai/a lb ai/a % v/v	7	bcd	2	d	0	c
11	Indaziflam (Alion) Gramoxone Inteon	0.044 0.5	lb ai/a lb ai/a	11	bc	60	b	55	b
12	Indaziflam (Alion) Gramoxone Inteon	0.065 0.5	lb ai/a lb ai/a	28	a	74	a	76	a
LSD (P=.05)				9.7		5.7		6.2	

Crop oil concentrate (COC) was included with all treatments at 1% (v/v) except #10, which included MSO. MSO = methylated seed oil.

Means followed by same letter do not significantly differ (P=.05, LSD)

Table 2. Tall hedge mustard and common lambsquarters control following eleven dormant applied herbicide treatments near Prosser, WA in 2011.

Pest Rating Date Rating Type				Tall hedge mustard May-6-2011 Control		Tall hedge mustard May-26-2011 Control		Common lambs quarters May-6-2011 Control		Common lambs quarters May-26-2011 Control	
Trt	Treatment	Rate	Unit	%		%		%		%	
1	Nontreated			0	d	0	d	0	c	0	c
2	Sulfentrazone (Spartan) Gramoxone Inteon	0.19 0.5	lb ai/a lb ai/a	53	c	25	d	100	a	100	a
3	Pyroxasulfone (KIH485) Gramoxone Inteon	0.19 0.5	lb ai/a lb ai/a	60	c	54	c	100	a	100	a
4	Pyroxasulfone (KIH485) Terbacil (Sinbar) Gramoxone Inteon	0.19 0.38 0.5	lb ai/a lb ai/a lb ai/a	98	ab	99	a	100	a	100	a
5	Sulfentrazone (Spartan) Clomazone (Command) Gramoxone Inteon	0.19 0.35 0.5	lb ai/a lb ai/a lb ai/a	98	ab	95	ab	100	a	100	a
6	SulfentrazoneCarfent (SpartanCharge)	0.21	lb ai/a	18	d	0	d	100	a	100	a
7	Flumioxazin (Chateau) Gramoxone Inteon	0.128 0.5	lb ai/a lb ai/a	70	bc	86	ab	100	a	100	a
8	Terbacil (Sinbar) Gramoxone Inteon	0.5 0.5	lb ai/a lb ai/a	100	a	100	a	100	a	100	a
9	Flumioxazin Pyroxasulfone (Fierce) Gramoxone Inteon	0.144 0.5	lb ai/a lb ai/a	70	bc	68	bc	100	a	100	a
10	Saflufenacil (Sharpen) Pendimethalin (Prowl) (MSO)	0.066 1 1	lb ai/a lb ai/a % v/v	13	d	19	d	100	a	99	ab
11	Indaziflam (Alion) Gramoxone Inteon	0.044 0.5	lb ai/a lb ai/a	7	d	0	d	98	b	100	a
12	Indaziflam (Alion) Gramoxone Inteon	0.065 0.5	lb ai/a lb ai/a	49	c	25	d	99	ab	99	b
LSD (P=.05)				28.59		28.02		2.24		0.65	

Crop oil concentrate (COC) was included with all treatments at 1% (v/v) except #10, which included MSO. MSO = methylated seed oil.
Means followed by same letter do not significantly differ (P=.05, LSD)

Table 3. Kochia control and peppermint hay and oil yield following eleven dormant applied herbicide treatments near Prosser, WA in 2011.

Pest Name Rating Date Rating Type Description Trt	Treatment	Rate	Unit	Kochia May-6-2011 Control %		Kochia May-26-2011 Control %		Jul-26-2011 Pepper. Hay Yield Ton/acre		Jul-26-2011 Pepper. Oil Yield Lbs/acre	
1	Nontreated			0	c	0	d	12.1	cd	55	de
2	Sulfentrazone (Spartan) Gramoxone Inteon	0.19 0.5	lb ai/a lb ai/a	100	a	100	a	14.0	abc	64	a-d
3	Pyroxasulfone (KIH485) Gramoxone Inteon	0.19 0.5	lb ai/a lb ai/a	100	a	99	a	15.1	a	72	abc
4	Pyroxasulfone (KIH485) Terbacil (Sinbar) Gramoxone Inteon	0.19 0.38 0.5	lb ai/a lb ai/a lb ai/a	100	a	100	a	15.2	a	68	a-d
5	Sulfentrazone (Spartan) Clomazone (Command) Gramoxone Inteon	0.19 0.35 0.5	lb ai/a lb ai/a lb ai/a	100	a	100	a	15.4	a	71	abc
6	SulfentrazoneCarfent (SpartanCharge)	0.21	lb ai/a	100	a	100	a	14.7	ab	79	a
7	Flumioxazin (Chateau) Gramoxone Inteon	0.128 0.5	lb ai/a lb ai/a	100	a	100	a	15.4	a	73	ab
8	Terbacil (Sinbar) Gramoxone Inteon	0.5 0.5	lb ai/a lb ai/a	3	c	13	c	12.2	c	61	b-e
9	Flumioxazin Pyroxasulfone (Fierce) Gramoxone Inteon	0.144 0.5	lb ai/a lb ai/a	98	ab	97	a	13.7	abc	62	bcd
10	Saflufenacil (Sharpen) Pendimethalin (Prowl) (MSO)	0.066 1 1	lb ai/a lb ai/a % v/v	20	c	84	b	13.0	bc	67	a-d
11	Indaziflam (Alion) Gramoxone Inteon	0.044 0.5	lb ai/a lb ai/a	75	b	5	cd	10.1	de	56	cde
12	Indaziflam (Alion) Gramoxone Inteon	0.065 0.5	lb ai/a lb ai/a	98	ab	10	cd	8.1	e	46	e
LSD (P=.05)				22.9		12.9		2.0		15.6	

Crop oil concentrate (COC) was included with all treatments at 1% (v/v) except #10, which included MSO. MSO = methylated seed oil.

Means followed by same letter do not significantly differ (P=.05, LSD)

Trial 2. A trial was established on a commercial peppermint field near Paterson, WA to evaluate redroot pigweed control with sulfentrazone (Spartan), pyroxasulfone (KIH-485), and bentazon (Basagran) plus terbacil (Sinbar) applied after the first cutting of double cut peppermint. Herbicides were applied with a small plot CO_2 sprayer delivering 25 GPA on July 29, 2011. All treatments included crop oil concentrate at 1% (v/v). Most pigweed was not emerged yet and pigweed that had emerged was 1 inch or less tall. Treatments were replicated four times in a randomized complete block design and a nontreated check was included.

Weed control and peppermint injury were evaluated twice in August and twice in September and mint hay and oil yield were collected and recorded on October 12, 2011. Final mint hay yield was determined by harvesting the center row of each plot and weighing. A 21 lb subsample of hay was dried from each plot and steam distilled to determine oil yield.

All treatments controlled redroot pigweed well indicating that the pigweed present in this field was not a Sinbar resistant biotype (Table 4). Herbicides were also applied soon after harvesting the mint so pigweed was very small or not yet germinated at the time of the application, which probably improved control. The trial also contained few established pigweed that were cut off during the first harvest, which are normally more difficult to control. A separate nonreplicated trial with sulfentrazone at 0.125 lb ai/a applied to established pigweed that were cut off during mint harvest was conducted in another section of the same field with very promising results. Sulfentrazone controlled or greatly suppressed established pigweed plants that had been cut off without any significant injury to the peppermint.

Although pyroxasulfone at 0.14 and 0.19 lb ai/a controlled pigweed well, it greatly stunted the regrowth of peppermint and injury was evident throughout the month of September (Tables 5 and 6). Sulfentrazone and terbacil plus bentazon treatments resulted in very slight or no injury on the peppermint. By early October, peppermint had recovered from most of the pyroxasulfone injury and new growth appeared normal. Peppermint treated with sulfentrazone at either rate or terbacil plus bentazon yielded the greatest amount of oil and hay (Table 6). Oil yield of weedy checks and plots treated with pyroxasulfone yield the least amount of oil and hay (Table 6).

Efforts to label sulfentrazone (Spartan) for applications following the first harvest of double cut mint are underway through the IR-4 program.

Table 4. Redroot pigweed control following five herbicide treatments applied after the first cutting in double cut peppermint near Paterson, WA in 2011.

Pest				Redroot pigweed		Redroot pigweed		Redroot pigweed		Redroot pigweed	
Rating Date				Aug-8-2011		Aug-17-2011		Sep-8-2011		Sep-20-2011	
Rating Type				Control		Control		Control		Control	
Trt.	Treatment	Rate	Unit	%		%		%		%	
1	Spartan (sulfentrazone)	0.063	lb ai/a	100	a	100	a	99	a	99	ab
2	Spartan (sulfentrazone)	0.125	lb ai/a	100	a	100	a	100	a	100	a
3	Pyroxasulfone (KIH485)	0.14	lb ai/a	95	a	96	a	98	a	99	b
4	Pyroxasulfone (KIH485)	0.19	lb ai/a	100	a	100	a	100	a	100	a
5	Sinbar	0.5	lb ai/a	100	a	100	a	99	a	100	a
	Basagran	1.0	lb ai/a								
6	Nontreated check			0	b	0	b	0	b	0	c
LSD (P=.05)				6.2		4.6		1.9		0.9	

Means followed by same letter do not significantly differ (P=.05, LSD).
All treatments included crop oil concentrate (COC) at 1% (v/v).

Table 5. Peppermint injury following five herbicide treatments applied after the first cutting in double cut peppermint near Paterson, WA in 2011.

Rating Date				Aug-17-2011		Sep-8-2011		Sep-20-2011		Oct-12-2011	
Rating Type				Injury		Injury		Injury		Injury	
Crop				Peppermint		Peppermint		Peppermint		Peppermint	
Trt	Treatment	Rate	Unit	%		%		%		%	
1	Spartan (sulfentrazone)	0.063	lb ai/a	0.3	c	5	b	1	c	0	c
2	Spartan (sulfentrazone)	0.125	lb ai/a	1	c	6	b	2	c	0	c
3	Pyroxasulfone (KIH485)	0.14	lb ai/a	4	b	50	a	33	b	6	b
4	Pyroxasulfone (KIH485)	0.19	lb ai/a	8	a	60	a	48	a	14	a
5	Sinbar Basagran	0.5 1.0	lb ai/a lb ai/a	1	c	1	b	2	c	0	c
6	Nontreated check			0	c	0	b	0	c	0	c
LSD (P=.05)				2.3		11.6		11.6		2.1	

Means followed by same letter do not significantly differ (P=.05, LSD)
All treatments included crop oil concentrate (COC) at 1% (v/v).

Table 6. Peppermint height, hay yield, and oil yield following five herbicide treatments applied after the first cutting in double cut peppermint near Paterson, WA in 2011.

Rating Date				Sep-20-2011		Oct-12-2011		Oct-12-2011	
Rating Type				Height		Hay yield		Oil yield	
Crop				Peppermint		Peppermint		Peppermint	
Trt	Treatment	Rate	Unit						
No.	Name			inches		Ton/acre		Lb/acre	
1	Spartan (sulfentrazone)	0.063	lb ai/a	9.1	ab	2.9	ab	18.9	a
2	Spartan (sulfentrazone)	0.125	lb ai/a	8.6	b	3.1	a	19.8	a
3	Pyroxasulfone (KIH485)	0.14	lb ai/a	7.3	c	2.1	cd	14.6	bc
4	Pyroxasulfone (KIH485)	0.19	lb ai/a	6.7	c	1.7	d	13.0	c
5	Sinbar	0.5	lb ai/a	8.9	ab	2.9	ab	17.6	ab
	Basagran	1.0	lb ai/a						
6	Nontreated check			9.8	a	2.5	bc	13.6	bc
LSD (P=.05)				0.95		0.62		4.13	

Means followed by same letter do not significantly differ (P=.05, LSD).
All treatments included crop oil concentrate (COC) at 1% (v/v).
Oil yield means were log transformed prior to analysis to meet data normality requirements.

Trial 3. White cockle (white campion, *Silene alba*) control in peppermint with fall and spring applied herbicides was evaluated in a trial located near Post Falls, ID. The soil was a gravely sandy loam. The site had a previous history of white cockle and some plants (2-3 in. diameter) were present in October 2010 when the trial was initiated. The trial was arranged as a split plot design with seven fall-applied herbicide treatments as main plots and three spring applied treatments as split plots. Treatments were replicated three times. Main plots (fall treatments) were 10 by 75 feet and split plots (spring treatments) were 10 by 25 feet.

Herbicides were applied with a small plot CO_2 sprayer delivering 25 GPA. Initial herbicide treatments were applied Oct. 5, 2010 when peppermint was still green and was 0.5 to 1 inch tall. Fall treatments included paraquat (Gramoxone Inteon) alone, flumioxazin (Chateau) plus paraquat, saflufenacil (Sharpen/Kixor) plus paraquat, clomazone (Command) plus paraquat, sulfentrazone plus paraquat, and fluroxypyr (Starane) plus paraquat (Table 7). All treatments included R-11 nonionic surfactant. Each of the six fall applied herbicide treatments were followed by spring applications of Command plus Gramoxone, Sinbar plus Gramoxone, or none on March 23, 2011 (Table 7).

White cockle control and mint injury were rated October 21, 2010, March 8, 2011, and May 19, 2011, and August 18, 2011. The number of white cockle plants per plot were recorded March 23, 2011 and May 19, 2011. Two selected treatments were harvested for peppermint hay and oil yield August 18, 2011.

Peppermint was desiccated with all fall-applied herbicide treatments in late October as all treatments contained paraquat (Gramoxone Inteon) which burned all green foliage present at the time of the herbicide application (Table 7). Peppermint injury the following spring was less than 10% with all fall applied treatments (Table 7). On May 19, 2011, spring treatment of Command plus Gramoxone injured peppermint slightly more than Sinbar plus Gramoxone. Peppermint injury was transient and normal mint growth resumed.

White cockle control at 2 weeks after treatment (WAT) in October was greatest with either Command, saflufenacil, or Chateau plus Gramoxone and least with Starane plus Gramoxone (Table 8). The following spring in March, all fall applied herbicide treatments resulted in statistically similar control of white cockle except Starane plus Gramoxone, which resulted in poorer control (Table 8). In May and August 2011, few or no white cockle was present in plots treated with Command plus Gramoxone or saflufenacil plus Gramoxone in the fall (Table 8). White cockle plant density in May 2011was greatest in nontreated plots, plots treated with only Gramoxone in the fall or with Starane plus Gramoxone in the fall (Table 8).

In August at the time of peppermint harvest, white cockle control was the greatest with fall treatments of saflufenacil or Command tank mixed with Gramoxone (Table 8). Fall applied Chateau or Spartan tank mixed with Gramoxone also provided good white cockle suppression. Command plus Gramoxone or Sinbar plus Gramoxone applied in March also reduced white cockle numbers regardless of the fall treatment (Table 2).

Saflufenacil and Command tank mixed with Gramoxone were both very promising treatments for white cockle control. Since saflufenacil is not labeled on mint, peppermint hay and oil yield were determined from the fall applied saflufenacil plus Gramoxone treatment that was followed by spring treatment with Sinbar plus Gramoxone and compared to fall applied Gramoxone/Spring Sinbar plus Gramoxone treatments. The treatments of saflufenacil plus Gramoxone yielded 11.8 ton fresh hay and 81 lbs oil/acre and those with Gramoxone alone/Sinbar plus Gramoxone yielded 12.4 ton fresh hay and 66 lbs oil/acre. Despite some initial peppermint injury from fall-applied saflufenacil plus Gramoxone, oil yield was not reduced compared to the Gramoxone alone fall treatment.

Table 7. Peppermint injury, oil yield and hay yield following fall and spring herbicide applications for white cockle control near Post Falls, ID in 2010-11.

Crop Rating Date Trt	 Treatment	 Rate	 Unit	Peppermint 10/21/2010 Injury	Peppermint 5/19/2011 Injury
TABLE OF A MEANS (Fall applications)				%	%
1	Nontreated Fall			0 c	2.8 b
2	Gramoxone Inteon	0.5	lb ai/a	94 ab	4.7 ab
3	Gramoxone Inteon	0.5	lb ai/a	98 a	4.6 ab
	Chateau	0.125	lb ai/a		
4	Gramoxone Inteon	0.5	lb ai/a	98 a	7.6 a
	Saflufenacil	0.044	lb ai/a		
5	Gramoxone Inteon	0.5	lb ai/a	94 ab	4.1b
	Command	0.5	lb ai/a		
6	Gramoxone Inteon	0.5	lb ai/a	97 ab	5.0 ab
	Spartan	0.19	lb ai/a		
7	Gramoxone Inteon	0.5	lb ai/a	92 b	1.7 b
	Starane	0.125	lb ai/a		
TABLE OF B MEANS (Spring applications)					
1	Sinbar	0.5	lb ai/a	---	2.5 b
	Gramoxone Inteon	0.5	lb ai/a		
2	Command	0.5	lb ai/a	---	8.2 a
	Gramoxone Inteon	0.5	lb ai/a		
3	Nontreated Spring			---	2.2 b

Fall treatments applied October 5, 2010 and spring treatments applied March 23, 2011.
Means within a column and application date followed by the same letter are not significantly different at P=0.05.
A means are averaged over all levels of B treatments. B means are averaged over all levels of A treatments.

Table 8. White cockle control following fall and spring applied herbicides near Post Falls, ID in 2010-11.

Pest				White cockle	White cockle	White cockle	White cockle
Rating Date				10/21/20	3/23/201	5/19/201	8/18/201
Trt	Treatment	Rate	Unit	Control	Control	No./plot	Control
TABLE OF A MEANS (Fall applications)				%	%	No.	%
1	Nontreated Fall			0	0	10	79 bc
2	Gramoxone Inteon	0.5	lb ai/a	70 b	74 ab	19	66 c
3	Gramoxone Inteon	0.5	lb ai/a	85 ab	84 ab	2	84 abc
	Chateau	0.125	lb ai/a				
4	Gramoxone Inteon	0.5	lb ai/a	78 abc	87 ab	0.2	100 a
	Saflufenacil	0.044	lb ai/a				
5	Gramoxone Inteon	0.5	lb ai/a	88 a	100 a	0.1	100 a
	Command	0.5	lb ai/a				
6	Gramoxone Inteon	0.5	lb ai/a	63 c	90 ab	4	92 ab
	Spartan	0.19	lb ai/a				
7	Gramoxone Inteon	0.5	lb ai/a	65 c	62 b	31	71 c
	Starane	0.125	lb ai/a				
TABLE OF B MEANS (Spring applications)							
1	Sinbar	0.5	lb ai/a	---	---	0.7 b	97 a
	Gramoxone Inteon	0.5	lb ai/a				
2	Command	0.5	lb ai/a	---	---	0.6 b	99 a
	Gramoxone Inteon	0.5	lb ai/a				
3	Nontreated Spring			---	---	27 a	58 b

Fall treatments applied October 5, 2010 and spring treatments applied March 23, 2011.
Means within a column and application date followed by the same letter are not significantly different at P=0.05.
Aug. 18, 2011 control data based on white cockle plants visible above mint canopy.
A means are averaged over all levels of B treatments. B means are averaged over all levels of A treatments.

<u>2. Determine the extent of herbicide resistant weeds in mint and determine their response to mint herbicides.</u>

In 2010, seed of nine different weed species from mint fields throughout the Columbia Basin in Washington were collected to ascertain the presence of herbicide resistant weeds. Redroot pigweed (*Amaranthus retroflexis*) and Powell amaranth (*A. powellii*) were the most prevalent weeds observed in late summer and were collected from 22 mint fields (Table 9). Other species collected include green foxtail (10 fields), barnyardgrass (3 fields), kochia (3 fields), and wild proso millet, common lambsquarters, common groundsel, horseweed (marestail, *Conyza canadensis*) and quackgrass from one field each (Table 9). All seed collection sites were georeferenced.

Weed seed was cleaned and planted in greenhouse flats. Each biotype was planted in 10 cm diameter containers replicated 4 to 6 times and grown in the greenhouse. Pigweed seedlings were thinned to eight plants per pot prior to applying the herbicides. Broadleaf weeds were treated with postemergence applied herbicides when they reached the 3 to 4 leaf stage and 1.5 to 2 inches tall. Grass weeds were treated when they reached the 3 to 4 leaf stage and were 3 to 4 inches tall. A single nozzle (80015 E) bench sprayer was used to apply herbicides treatments to plants. The sprayer was calibrated to deliver 25 GPA.

Initially, weed biotypes were treated with a ½ X and 1X labeled rate of the specific herbicide in question. A susceptible biotype of each species was included in each experiment as a control. Weed biotypes that were not completely killed by the ½ X or 1X rate of the herbicide were further tested with a range of six or seven doses of the herbicide to determine the dose response of the resistant biotype compared to the susceptible control. The number of surviving seedlings, dry weights, and visual control rating were recorded at two weeks after herbicide application.

Dose response curves of each weed biotype were compared to the susceptible biotype (indigenous population) of the same species. The I_{50} (also known as GR_{50} = dose required to reduce growth or shoot weight by 50% relative to untreated plants) of the resistant and susceptible populations was determined using the log logistic analysis package of the 'R' statistical program. The dose required to provide 90% control (I_{90}) was also calculated from the dose response curve.

Weed biotypes with confirmed resistance were further tested for susceptibility to herbicides with other modes of action that are labeled in mint. Seeds were planted in 10 cm diameter pots and treated with normal labeled rates of each herbicide either preemergence or postemergence depending on the herbicide. A normal susceptible biotype was included as a control for comparison in each experiment.

Results.

Redroot pigweed (*Amaranthus retroflexis*) and Powel amaranth (*A. powellii*).

Nine of 22 pigweed biotypes tested were resistant to terbacil (Tables 9 and 10). All 9 terbacil resistant biotypes were also resistant to metribuzin. Dose response analysis based on I_{90} values (dose required to provide 90% control) indicated that 3.4 to 17.3 times as much herbicide was required to provide 90% control the resistant biotypes compared to the susceptible control (Table 10).

Weed seed was also collected from fields of potato, sweet corn, and dry beans in 2010. Pigweed and common lambsquarters were collected from potato, sweet corn, and dry bean fields in the Columbia Basin and were screened for resistance to metribuzin, a photosystem II inhibitor herbicide that has a similar mode of action to terbacil. Fifteen metribuzin resistant pigweed biotypes were confirmed out of 27 biotypes tested and all

15 were cross resistant to terbacil (Table 9). Likewise, 8 common lambsquarters biotypes with confirmed resistance to metribuzin that were collected from potato fields were cross resistant to terbacil. All 11 terbacil resistant pigweed biotypes collected from mint fields also proved to be cross resistant to metribuzin. Triazine (metribuzin) and uracil (terbacil) herbicides inhibit P.S. II in plants by binding to the Qb protein in the chloroplast and inhibit electron transport. These two herbicide families have overlapping binding sites and similar mutations in the Qb protein typically confer resistance to both herbicide families.

All 27 pigweed biotypes collected from potato, sweet corn, and dry bean fields were susceptible to rimsulfuron (Matrix) at 0.0012 lb ai/a.

Initial greenhouse studies indicate that flumioxazin (Chateau) and trifluralin (Treflan) applied preemergence at normal use rates control all terbacil and metribuzin resistant pigweed biotypes. Susceptibility of pigweed to pendimethalin (Prowl) at 0.75 lb ai/a was less than that of flumioxazin and trifluralin, but terbacil resistant pigweed biotypes were suppressed by pendimethalin equal to the normal susceptible biotype. In preliminary studies, all 11 terbacil resistant pigweed biotypes from mint were susceptible to bromoxynil at 0.5 lb ai/a and bentazon at 1 lb ai/a applied postemergence similar to the susceptible control.

Grass weeds (barnyardgrass, green foxtail, wild proso millet, and quackgrass)
The four grass species that were collected; green foxtail, barnyardgrass, wild proso millet, and quackgrass were screened for susceptibility to clethodim (Select) and sethoxydim (Poast), two postemergence grass herbicides with similar mode of action. Quackgrass was also screened for susceptibility to quizalofop (Assure II), which has a similar mode of action to sethoxydim and clethodim.

Grass seedlings were treated with each herbicide when seedlings reached 3 to 4 leaf stage and a susceptible biotype (collected from areas with no known herbicide resistance) of each species was included in each experiment. All of the grass weed biotypes collected from mint fields were susceptible to either a 0.5 and 1 X rate of clethodim, sethoxydim, or quizalofop and the response was similar to that of the susceptible control biotypes (Tables 11 and 12). None of these grass populations appear to be resistant to this group of postemergence grass herbicides.

Kochia (*Kochia scoparia*).
The response of three kochia biotypes collected from mint fields to mint herbicides have not been tested yet.

Horseweed (*Conyza canadensis*)
Horseweed collected from mint was susceptible to a 0.5 lb ai/a rate of bromoxynil, but paraquat at 0.5 lb ai/a failed to control the weed, whereas the susceptible horseweed control biotype was killed (Table 13). A follow up dose response study will be conducted with paraquat to determine the level of resistance.

Common groundsel (*Scenecio vulgaris*)
Common groundsel was survived treatment with 0.5 lb ai/a terbacil, but was susceptible to bromoxynil at 0.5 lb ai/a. Common groundsel has a long history of resistance to P.S. II inhibitors, such as terbacil, and we were not able to locate a terbacil susceptible biotype.

Common lambsquarters (*Chenopodium album*)
Common lambsquarters collected from mint did not contain any germinable seed so no studies were conducted. Eight of 25 common lambsquarters biotypes collected from potato fields in the Columbia Basin were resistant to metribuzin and were cross resistant to terbacil.

Table 9. Weed seed populations collected from potato, sweet corn, dry bean, and mint fields throughout the Columbia Basin in 2010-11.

Crop	Weed Species	Binomial	Number of Samples	Number of Resistant	Herbicide
2010					
Potato	Pigweed	*Amaranthus retroflexis, A. powellii*	25	15	metribuzin
	C. lambsquarters	*Chenopodium album*	25	8	metribuzin
	Hairy nightshade	*Solanum physalifolium*	4	0	rimsulfuron
	Barnyardgrass	*Echinochloa crus-galli*	2	0	sethoxydim/ clethodim
	Green foxtail	*Setaria viridis*	1	0	sethoxydim/ clethodim
Sweet Corn	Pigweed	*A. retroflexis*	1	1	metribuzin
Dry bean	Pigweed	*A. retroflexis*	1	0	metribuzin
	C. lambsquarters	*C. album*	1	na	
Mint	Pigweed	*A. retroflexis, A. powellii*	22	9	terbacil
	C. lambsquarters	*C. album*	1	na	
	Barnyardgrass	*E. crus-galli*	3	0	sethoxydim/ clethodim
	Green foxtail	*S. viridis*	10	0	sethoxydim/ clethodim
	Kochia	*Kochia*	3	na	

		scoparia			
	C. groundsel	*Senecio vulgaris*	1	1	terbacil
	Horseweed	*Conyza Canadensis*	1	1	paraquat
	Wild proso millet	*Panicum miliaceum*	1	0	sethoxydim/ clethodim
	Quackgrass	*Elymus repens*	1	0	sethoxydim/ clethodim/ quizalofop
2011					
Blueberry	Horseweed	*C. Canadensis*	1	na	
Potato	Kochia	*K. scoparia*	1	na	
Onion	C. lambsquarters	*C. album*	1	na	
Potato	C. lambsquarters	*C. album*	1	na	

na = no data available yet or seed not viable.

Table 10. Response of 22 pigweed biotypes collected from Washington mint fields to postemergence applied terbacil in the greenhouse. (I_{50} = dose required to reduce growth by 50% and I_{90} = dose required to reduce growth by 90%). Numbers in parenthesis are relative resistance to susceptible control.

Biotype	Percent Injury (2 WAT)		I_{50}	I_{90}
	(.25 lb ai/a)	(.5 lb ai/a)	(lb ai/a)	(lb ai/a)
Susc. CK	100	100	0.19	0.40
M1	100	100	--	--
M2	99.8	100	--	--
M3	100	100	--	--
M4	**16-48**	**71**	**1.32 (6.9 X)**	**4.79 (12.0 X)**
M5	**53**	**67**	**0.97 (5.1 X)**	**2.83 (7.1 X)**
M6	100	100	--	--
M7	100	100	--	--
M8	100	100	--	--
M9	100	100	--	--
M10	**28**	**36**	**0.86 (4.5 X)**	**2.42 (6.1 X)**
M11	**23**	**33**	**0.56 (2.9 X)**	**1.34 (3.4 X)**
M12	100	99.4	--	--
M13	**32**	**51**	**0.93 (4.9 X)**	**2.23 (5.6 X)**
M14	**12-20**	**49**	**1.34 (7.1 X)**	**6.93 (17.3 X)**
M15	**17-50**	**89**	**0.89 (4.7 X)**	**4.69 (11.7 X)**
M16	96	na	--	--
M17	93	na	--	--
M18	75	na	0.20*	0.44*
M19	67	na	0.15*	0.36*
M20	**16**	**na**	**1.13 (5.9 X)**	**3.05 (7.6 X)**
M21	**16**	**na**	**0.73 (3.8 X)**	**1.87 (4.7 X)**
M22	96	na	--	--

*Dose response of biotype similar to susceptible control.
Biotypes in boldface tested resistant to terbacil.

Figure 1. Response of six pigweed biotypes collected from mint fields and a susceptible biotype (CK) to terbacil applied at seven doses.

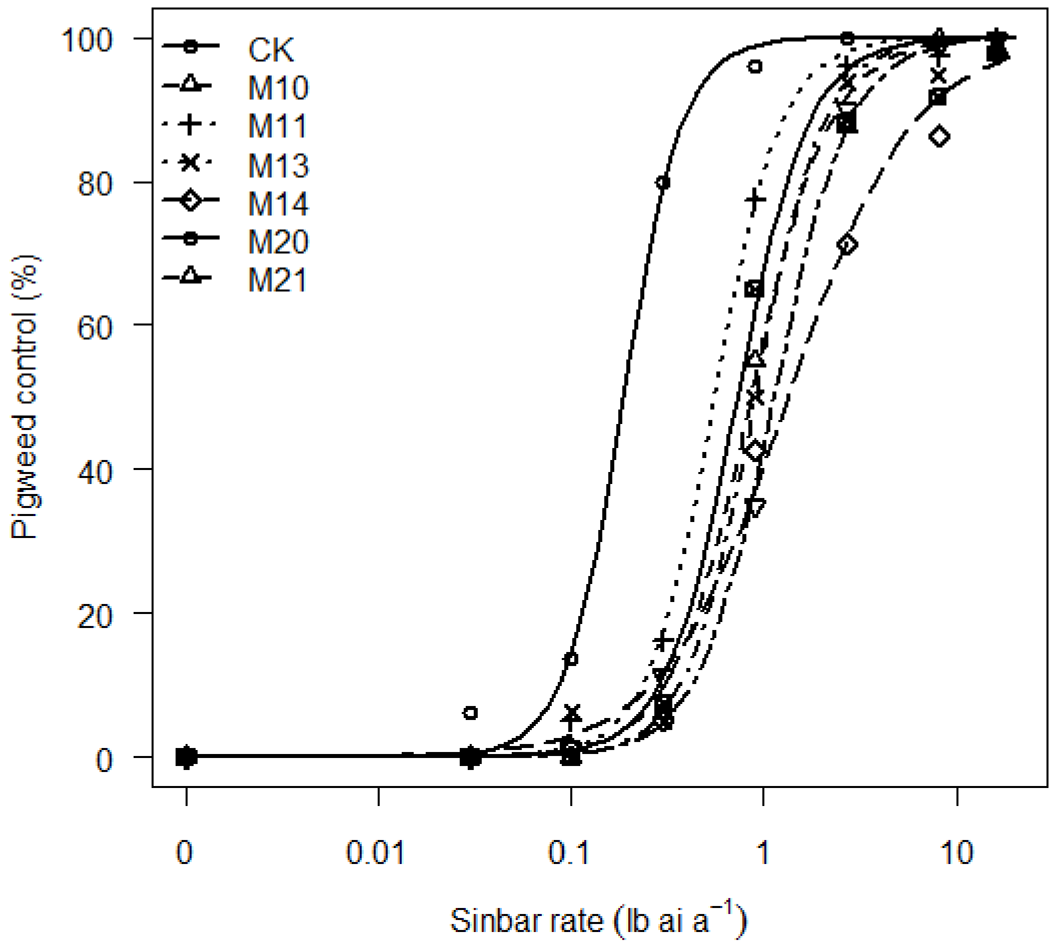

Table 11. Response of barnyardgrass, green foxtail, and wild proso millet biotypes collected from Washington mint fields to sethoxydim and clethodim at two doses in greenhouse trials.

	Percent Control (2 WAT)			
	Sethoxydim		Clethodim	
Species/Biotype	0.125	0.25	0.047	0.094
	(%)	(%)	(%)	(%)
Barnyardgrass				
Susceptible control	99	100	65	97
M23	99	100	83	100
M24	99	100	78	99
M25	99	99	74	99
Green foxtail				
Susceptible control	98	100	80	90
M26	97	--	96	99
M27	92	99	87	96
M28	96	100	97	99
M29	92	99	96	98
M30	94	95	96	98
M31	91	98	96	98
M32	97	100	97	98
M33	97	99	97	98
M34	98	--	99	99
M35	100	100	97	99
Wild proso millet				
Susceptible control	100	100	90	97
M42	100	100	91	100

Crop oil concentrate (COC) was included in all treatments at 1% (v/v).

Table 12. Response of two quackgrass biotypes to three postemergence grass herbicides; clethodim, sethoxydim, and quizalofop applied at two rates in greenhouse trials.

Quackgrass Biotype	Herbicide	Rate	Control 21 DAT	Dry wt. 24 DAT
		(Lb ai/a)	(%)	Percent of nontreated control
M QG	clethodim	0.047	46	56
M QG	clethodim	0.094	78	17
Susceptible CK	clethodim	0.047	46	98
Susceptible CK	clethodim	0.094	79	30
M QG	sethoxydim	0.19	96	20
M QG	sethoxydim	0.38	99	17
Susceptible CK	sethoxydim	0.19	89	26
Susceptible CK	sethoxydim	0.38	97	18
M QG	quizalofop	0.034	94	40
M QG	quizalofop	0.069	100	42
Susceptible CK	quizalofop	0.034	96	35
Susceptible CK	quizalofop	0.069	100	28

Crop oil concentrate was included in all treatments at 1% (v/v).

Table 13. Response of two horseweed biotypes to paraquat and bromoxynil in greenhouse trials.

Horseweed Biotype	Herbicide	Rate	Control 2 WAT
		(Lb ai/a)	(%)
M HW	paraquat	0.5	55
Susceptible CK	paraquat	0.5	100
M HW	bromoxynil	0.5	100
Susceptible CK	bromoxynil	0.5	100

Nonionic surfactant was included in all treatments at 0.25% (v/v).

3. Determine the response of *Potentilla paradoxa* and *Rorippa islandica* (Marsh yellow cress) to mint herbicides.

In 2010, several mint fields in the Columbia Basin contained two weeds that previously hadn't been reported to be problems in mint production; *Potentilla paradoxa* and *Rorippa islandica* (Marsh yellow cress) (Fig. 2). A field consultant in the region indicated that these two weeds had been difficult to eliminate using their current herbicide program in mint. Seed was collected and greenhouse studies were initiated on these two species to determine their response to common herbicides labeled in mint production.

Each species was seeded into 10 cm diameter containers filled with sandy loam soil. For preemergence (PRE) trials, enough seed was sown to obtain 10 to 15 seedlings per pot in nontreated checks. For postemergence (POST) trials, seedlings were thinned to three plants per pot before treating. Plants were treated with POST applied herbicides when cress and potentilla seedlings averaged 1.5 inch diameter with 3 to 4 leaves. Herbicides were applied using a single nozzle bench sprayer delivering 25 GPA through an 80015 flat fan nozzle. Herbicide treatments were replicated 4 or 5 times in a completely randomized design. Standard labeled rates of each herbicide were used to determine response of each weed to the herbicides tested (Table 14). Each PRE and POST trial was repeated once. Plants were grown in the greenhouse during the first POST trial. In the second POST trial, plants were germinated in the greenhouse and then placed outside before spraying and for the remainder of the experiment.

Spartan, Chateau, Goal, Karmex, Command, and Sinbar all completely or nearly completely controlled both species when applied PRE at labeled rates (Table 14). Of the PRE herbicides tested, only Prowl H2O failed to completely control these two species. Prowl significantly reduced the number of cress (*Rorippa islandica*) seedlings per pot and injured both species, but injury was much less to the *Potentilla paradoxa* and a greater number of seedlings survived (Table 14).

Basagran applied POST controlled cress (*Rorippa islandica)* about 90% and *Potentilla paradoxa* 82% (Table15). Buctril applied POST controlled *Potentilla paradoxa* about 95%, but only suppressed *Rorippa islandica* from 63 to 93% (Table 15). Thistrol did not control *Rorippa islandica*, but controlled *Potentilla paradoxa* from 77 to 100% (Table 15). POST applied Stinger failed to control either weed, but stunted the growth of *Potentilla paradoxa* from 24 to 95% and that of *Rorippa islandica* 7 to 25% (Table 15).

It appears these two species can be controlled in mint with the proper timing of PRE herbicides. Partial to nearly complete control of weeds that escape PRE treatments could be accomplished with Basagran or Buctril applied early POST to small seedlings, depending on the species in question.

Table 14. Cress and potentilla control following seven PRE applied herbicide treatments in greenhouse trials in 2011.

Treatment	Rate	Cress Control 28 DAT	Cress Counts/pot 28 DAT	Potentilla Control 28 DAT	Potentilla Counts/pot 28 DAT
	(Lb ai/a	(%)	(no./pot)	(%)	(no./pot)
Nontreated	--	0 c	12.3 a	0 c	12.3 a
Spartan	0.19	100 a	0 b	100 a	0 c
Chateau	0.125	100 a	0 b	100 a	0 c
Goal	0.38	100 a	0 b	100 a	0 c
Karmex	1.0	100 a	0 b	100 a	0 c
Prowl	1.0	95 b	1 b	58 b	6.1 b
Command	0.38	100 a	0 b	100 a	0 c
Sinbar	0.5	99 a	0.1 b	100 a	0 c

Table 15. Cress and potentilla control following four POST applied herbicide treatments in greenhouse (trial 1) and outdoor (trial 2) pots in 2011.

Treatment	Rate	Cress Control Trial 1 28 DAT	Cress Control Trial 2 28 DAT	Potentilla Control Trial 1 20 DAT	Potentilla Control Trial 2 20 DAT
	Lb ai/a	%	%	%	%
Nontreated		0 d	0 d	0 c	0
Basagran	1	83 a	100 a	79	84
Buctril	0.38	63 b	93 b	93	97
Thistrol	0.5	42 c	57 c	100	77
Stinger	0.19	25	7	95	24

Figure 2. *Potentilla paradoxa* seedling (left) and *Rorippa islandica* seedling (right).