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Author(s): Jeffery S. Conn and Steven S. Seefeldt
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Invasive White Sweetclover (*Melilotus officinalis*) Control with Herbicides, Cutting, and Flaming

Jeffery S. Conn and Steven S. Seefeldt*

White sweetclover is invading the Alaska glacial river floodplains and roadsides adjacent to natural areas, and control methods are needed. Chlorsulfuron, 2,4-DB, clopyralid, triclopyr, and 2,4-D controlled white sweetclover seedlings below recommended rates in the greenhouse. Biomass of established plants in the field was reduced by chlorsulfuron at recommended (17.6 g ai/ha), 1/2, and 1/4 rates and was reduced by triclopyr and 2,4-D at recommended rates (1,260 and 1,600 g ai/ha). Herbicides were more effective at reducing white sweetclover viable seed production in 2007 than in 2006. Only chlorsulfuron at 17.6 g ai/ha (recommended rate) eliminated seed production in both years. Flaming killed first-year plants, but some second-year plants resprouted and produced viable seed. Cutting at the 2.5 or 10 cm height did not control first-year plants because of regrowth, and second-year plant density and seed production was reduced by cutting at 2.5 cm but not by cutting at 10 cm.

Nomenclature: Chlorsulfuron; clopyralid; 2,4-D; 2,4-DB; dicamba; triclopyr; white sweetclover, *Melilotus officinalis* (L.) Lam.

Key words: Invasive species, chemical weed control, flaming, burning, cutting.

White sweetclover [*Melilotus officinalis* (L.) Lam.] originated in Europe and Asia and was introduced to Alaska in 1913 as a forage and nitrogen-fixing crop (Irwin 1945). It is a biennial that can produce up to 350,000 seeds/plant (Klebesadel 1992; Turkington et al. 1978). First-year plants rarely grow taller than 30 cm and mainly allocate resources to development of a perennating root structure, whereas second-year plants are taller (to 200 cm) and allocate more energy to reproduction (Turkington et al. 1978). The original Alaska white sweetclover introductions had little winter hardiness (Irwin 1945) and exhibited an annual life history (Klebesadel 1992, 1994). Over time, the species gradually shifted to a biennial life cycle in Alaska (Klebesadel 1994). It has since escaped cultivation, invading roadsides, disturbed areas, and the glacial river floodplains of the Stikine, Matanuska, and Nenana rivers (Conn et al. 2008).

White sweetclover is present in all 50 U.S. states (USDA NRCS 2008); is spreading in western Greenland (Polunin 1959), the Yukon, and the Northwest Territories of Canada (Turkington et al. 1978); and is invading floodplains in northern Montana (Pearce and Smith 2003), the Yukon, southern Ontario, the prairies of the midwestern United States (Turkington et al. 1978), and the Rocky Mountain National Park in Colorado (Wolf et al. 2003).

White sweetclover exhibits a wide geographic range. In Alaska, it occurs north of the Arctic Circle at a site (67°9′N latitude) with < 17 cm annual precipitation and wintertime temperatures as low as −50 C, and as far south as the town of Ketchikan, AK (55°8′60″N latitude), where temperatures are milder and annual precipitation averages 394 cm (Conn et al. 2008). Sweetclover forms nitrogen-fixing root nodules with *Rhizobium* bacteria. Nitrogen-fixing invasive species can be community transformers (Rejmánek et al. 2005; Richardson et al. 2000) as increased soil N can facilitate the establishment of other invasive plant species (Vitousek and Walker 1989). On Alaska's Matanuska and Stikine River floodplains, low to moderate density of white sweetclover was positively correlated with the exotic species narrowleaf hawksbeard (*Crepis tectorum* L.) and common dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers) (J. S. Conn, personal observation). Along the Stikine River, high white sweetclover density and cover was strongly and negatively correlated with common dandelion and several native species, including beach pea

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* Research Agronomists, U.S. Department of Agriculture, Agricultural Research Service, Subarctic Research Unit, 360 O'Neil Building, University of Alaska Fairbanks, Fairbanks, AK 99775. Corresponding author's E-mail: Jeff.Conn@ars.usda.gov

Interpretive Summary

White sweetclover is spreading in urban areas, roadsides, and glacial floodplains in Alaska, and effective methods are needed to limit competition and to eradicate new populations. White sweetclover is a biennial, and populations can contain either all first-year, all second-year, or mixed-age plants. We studied the effectiveness of the herbicides chlorsulfuron, 2,4-DB, clopyralid, dicamba + diflufenzopyr, triclopyr, and 2,4-D for controlling seedling white sweetclover using greenhouse studies. All herbicides, except 2,4-DB, reduced dry matter of seedlings at rates below recommended doses. Based on these results, we studied whether chlorsulfuron, clopyralid, triclopyr, and 2,4-D effectively controlled established white sweetclover plants in the field. Efficacy of flaming and cutting was also investigated. In the field, biomass of established plants was reduced by chlorsulfuron at recommended (17.6 g ai/ha; 0.016 lb ai/ac), 1/2, and 1/4 rates and was reduced by triclopyr and 2,4-D at recommended rates (1,260 and 1,600 g ai/ha; 1.11 and 1.4 lb ai/ac). Herbicides were more effective at reducing white sweetclover viable seed production in 2007 than in 2006. Only chlorsulfuron at 17.6 g ai/ha (recommended rate) eliminated seed production in both years. Flaming killed first-year white sweetclover, but some second-year plants resprouted, and viable seed was produced. Cutting white sweetclover at either 2.5 (1 in) or 10 cm (4 in) height above the ground did not effectively control first-year plants because of regrowth below the cut. Density and viable seed production of second-year plants was reduced by cutting at 2.5 cm but not by cutting at 10 cm above the ground.

(*Lathyrus japonicus* Willd.) and feltleaf willow [*Salix alaxensis* (Anderss.) Coville] (J. S. Conn, personal observation). Spellman (2008) found 50% fewer seedlings of native species occurred in plots where white sweetclover was growing in dense populations on the Nenana River floodplain in Alaska compared with plots where white sweetclover had been removed.

Effective methods to control white sweetclover are needed in Alaska. Sweetclover seeds may disperse from roadside populations onto floodplains at places where roads intersect with river corridors (Macander et al. 2007). Because its seeds can remain viable in soil for at least 20 yr (Stoa 1933), measures that prevent seed production and subsequent establishment of new populations are needed.

Several different options have been tested for white sweetclover control. The species is reported to be susceptible to 2,4-D, 2,4-DB, MCPA, dicamba, picloram, and dalapon (Turkington et al. 1978). Mowing can also be used. Cutting first-year sweetclover in late summer, when translocation to roots is just beginning, has been shown to greatly reduce winter survival (Klebesadel 1994, Martin 1934). Prescribed burning for control of white sweetclover in grasslands has been investigated. The success of burning varied on whether the stand was even-aged or mixed-age and on the time and intensity of burning (Eckardt 1987). Burning even-aged stands before seed set prevented seed release. For mixed-age stands, burning before seed set for 3 to 5 yr seemed to be the most effective control procedure.

The objectives of this study were to (1) screen herbicides for controlling seedling white sweetclover at recommended and reduced rates using greenhouse studies, (2) test herbicides that were effective in the greenhouse on established white sweetclover in a field environment, and (3) evaluate cutting and flaming as alternatives to chemical control methods.

Methods

Chemical Control. *Greenhouse Studies.* Greenhouse experiments were conducted at Palmer, AK, in the fall and winter of 2005 to 2006 to determine the effect of chlorsulfuron, 2,4-DB, clopyralid, dicamba + diflufenzopyr, triclopyr, and 2,4-D on seedling white sweetclover. The greenhouse was maintained at 15 to 20 C (59–68 F) with supplemental lighting in a 12/12 h day/night cycle. Supplemental lighting was not available for the first 4 wk in 2005. White sweetclover seed was collected from dense populations on the Nenana River floodplain near Rex Bridge, AK, in 2004 and 2005. Based on our preliminary studies on methods to break primary dormancy in white sweetclover, we soaked the seed in concentrated sulfuric acid (98%) for 1 h and then triple-rinsed with distilled water before planting. Three seeds were planted in each 60-ml (2 fl oz) pot filled with sterilized potting soil[1] (2005) or an artificial potting mix[2] (2006). Plants were watered daily and thinned to one seedling per pot 2 to 3 wk after planting. Herbicides were applied at the two- to three-leaf stage using a handheld variable rate log-step sprayer[3] with a flat-fan nozzle delivering 200 L/ha (21 gal/ac). Before spraying on application day, 10 representative plants were harvested at the soil level, dried at 60 C (140 F) for 4 d, and weighed to determine initial dry weights. Two weeks after treatment, all plants were harvested at the soil level, dried at 60 C for 4 d, and weighed. Dry matter accumulation (DMA) after spraying was determined by subtracting the average initial weights from final weights for each experiment. Both greenhouse experiments were conducted using a randomized complete-block design with four replicates. Control plants were sprayed with water and were included for each herbicide. Application rates in the first greenhouse experiment ranged from the manufacturer-recommended field-use labeled rate (1×) to 1/16 of that rate. Because all the plants sprayed at either the 1× or the 1/2× doses were killed in the first experiment (for all herbicides tested, except 2,4-DB), we deleted the 1× rate and, except for the dicamba + diflufenzopyr treatment, substituted a 1/32× rate (Table 1) when we repeated the experiment (experiment 2).

Field Studies. The ability of 2,4-D, chlorsulfuron, triclopyr, and clopyralid to control established white sweetclover biomass and viable seed production was studied in separate

Table 1. Effect of herbicides on white sweetclover dry matter accumulation (DMA) in two greenhouse experiments. Manufacturer labeled rates are designated as 1×. Values are means (± SE; n = 4).[a]

Herbicide treatment	Rate	DMA	
		Experiment 1	Experiment 2
	g ai/ha	mg	
Chlorsulfuron control	0	63 a	80 a
Chlorsulfuron 1/32×	0.6	—[b]	46 b
Chlorsulfuron 1/16×	1.1	19 b	46 b
Chlorsulfuron 1/8×	2.2	13 bc	42 b
Chlorsulfuron 1/4×	4.4	11 bc	45 b
Chlorsulfuron 1/2×	8.8	10 bc	30 b
Chlorsulfuron 1×	17.6	12 bc	—[b]
Clopyralid control	0	65 a	67 a
Clopyralid 1/32×	7	—[b]	73 a
Clopyralid 1/16×	13	45 b	39 b
Clopyralid 1/8×	26	19 cd	37 b
Clopyralid 1/4×	53	16 d	16 c
Clopyralid 1/2×	105	15 d	14 c
Clopyralid 1 ×	210	10 d	—[b]
Dicamba + diflufenzopyr control	0 + 0	69 a	58 a
Dicamba + diflufenzopyr 1/16× + 1/16×	1.6 + 0.7	69 a	49 a
Dicamba + diflufenzopyr 1/8× + 1/8×	3.3 + 1.3	55 b	26 b
Dicamba + diflufenzopyr 1/4× + 1/4×	6.5 + 2.6	37 c	13 c
Dicamba + diflufenzopyr 1/2× + 1/2×	13 + 5.3	16 d	8 c
Dicamba + diflufenzopyr 1× + 1×	26 + 11	12 d	—[b]
Triclopyr control	0	71 a	90 a
Triclopyr 1/32×	20	—[b]	75 a
Triclopyr 1/16×	79	64 a	52 b
Triclopyr 1/8×	160	45 b	33 bc
Triclopyr 1/4×	320	30 bc	18 c
Triclopyr 1/2×	630	15 bcd	17 c
Triclopyr 1×	1260	17 bcd	—[b]
2,4-D control	0	64 a	100 a
2,4-D 1/32×	50	—[b]	72 b
2,4-D 1/16×	100	40 b	46 c
2,4-D 1/8×	200	20 c	36 cd
2,4-D 1/4×	400	12 d	20 e
2,4-D 1/2×	800	13 d	22 de
2,4-D 1 ×	1600	10 d	—[b]

[a] In each experiment, means within a herbicide followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

[b] In the second experiment, the 1× rate was eliminated for all herbicides because of the total kill in the first experiment and there were no differences in white sweetclover DMA between the 1× and 1/2× doses. A rate 1/32× of the recommended use rate was substituted. The 1/32 dose was not applied in the first experiment.

experiments performed in 2006 and 2007, using a large, naturally occurring, mixed-age field population of white sweetclover on private land in Fairbanks, AK. The soil was sand and gravel fill. Plots were 1.8 m by 9.1 m (6 ft by 30 ft), arranged in a randomized complete-block design, with three blocks. Treatments were four herbicides at three rates (1×, 1/2×, and 1/4×) and a weedy control. Treatments were applied when first-year plants were at the 2- to 10-leaf stage and when second-year plants were to 0.5 m tall and had initiated flowering. In 2006, treatments were applied on June 23 and, in 2007, on June 18. We used a handheld variable-rate log-step sprayer[3] with a 1.8-m (5.9 ft) boom, employing flat-fan nozzles[4] delivering 200 L/ha. Plants were visually rated for control on August 3, 2006, and September 4, 2007, using a 0 (no difference from control) to 100% (all plants dead) scale. We harvested white sweetclover plants within a 1-m by 1-m (3.3 ft by 3.3 ft) subplot in each plot at the soil level on September 8 in the 2006 study and on September 15 in the 2007 study. Seeds were then removed from the plants and were air dried for 3 wk on a laboratory bench before weighing, counting, and testing for viability. Remaining biomass was dried at 60 C for 4 d and weighed.

Flaming and Cutting Studies. We examined the effect of cutting and burning on white sweetclover biomass and seed production in a dense white sweetclover infestation just downstream from the Rex Bridge, AK, on the Nenana River (64°13′34.2″N, 149°17′7.86″W; elevation 211 m [693 ft]). The site was on a braided glacial river floodplain with unconsolidated boulders, sand, and gravel soil. Two separate trials were conducted, in 2004 and 2005, each using 3.1 m by 3.1 m (10 ft × 10 ft) plots. Treatments were (1) flaming with a weed burner propane torch,[5] (2) cutting at 2.5 cm (1 in) above the soil surface, (3) cutting at 10 cm (4 in) above the soil surface with a gasoline-powered lawn trimmer,[6] and (4) a control. The two cutting heights were chosen to simulate several possible mowing scenarios: The 10-cm cutting height simulated roadside mowing with the mower set to a level to avoid hitting rocks, and the 2.5-cm cutting height simulated ground-level mowing, practical on a small scale with hand-operated equipment. To flame the plots, the weed-burning torch was swept from side to side as the operator moved forward at a slow walk. All portions of the plants were subjected to flame, but the plants were not burned black. The experiment was designed as a randomized complete-block with three blocks in 2004 and four blocks in 2005. Treatments were executed in 2004 on July 8, when first-year white sweetclover was in the 6- to 12-leaf stage, and second-year sweetclover was 0.5 to 1.0 m (1.7 ft to 3.3 ft) tall and flowering. In 2005, treatments were applied June 28, when sweetclover was at similar growth stages as in 2004.

On September 22, 2004, and September 23, 2005, the number of surviving first- and second-year plants was determined in each plot. Seeds were collected from all plants in a 0.5 m by 0.5 m (1.7 ft by 1.7 ft) subplot, air-dried for 3 wk on a laboratory bench, counted, and tested for viability.

Seed Viability Testing. We measured the viability of white sweetclover seeds produced in both the field herbicide and in the cutting and burning experiments using the methods of Conn and Farris (1987) with slight modifications. For the field herbicide study, 100 seeds from each replicate of each treatment were tested, or when fewer than 100 seeds were produced (three plots), all of the seed were used for viability testing. For the cutting and flaming experiments, 150 seeds from each replicate of treatment were tested, except in instances where fewer than 150 seeds were produced, and all seeds available were tested. The seeds were placed on moist filter paper and incubated in the dark for 2 wk at 12 C (54 F). Seed coats of seeds that did not germinate were scarified with concentrated sulfuric acid for 60 min and rinsed with distilled water three times. The seeds were then incubated for an additional 7 d, and the germinants were recorded and then discarded. Nongerminated seeds were then placed in a 3,000-ppm, 2,3,5-triphenyltetrazolium chloride (TTC) solution (pH 7.0) for 7 d. Seeds were then dissected, and seeds with pink to red embryos were recorded as viable.

Statistical Analyses. Data were analyzed as randomized complete-block designs using the generalized linear model (GLM) procedure of SAS.[7] ANOVA assumptions were tested before analysis assumptions using the univariate procedure and Levene's test in SAS. Fisher's Protected LSD test was used to separate means.

Greenhouse Study. DMA data met ANOVA assumptions and were not transformed. We analyzed each greenhouse experiment separately because the two experiments differed in the highest and lowest rates. Within experiments, response to each herbicide was analyzed separately.

Field Herbicide Control. Biomass, plant density, and viable seed data were log-transformed, and percentage of control data was transformed using arcsine square root. If significant treatment by year interactions were not found for a particular response variable, data were combined for both years.

Flaming and Cutting Studies. Density and number of viable seeds data were log-transformed. Separate analyses were done for first-year and second-year white sweetclover and for both age classes together.

Results and Discussion

Chemical Control. *Greenhouse Studies.* In both experiments, chlorsulfuron, clopyralid, triclopyr, 2,4-D, and the dicamba–diflufenzopyr mixture at recommended application rates and at reduced rates decreased seedling white sweetclover DMA compared with controls (Table 1). Both chlorsulfuron and 2,4-D decreased DMA below control levels even at 1/32 of the recommended rate. No significant differences were found in white sweetclover seedling DMA when chlorsulfuron was applied at the recommended (1× = 17.6 g ai/ha; 0.016 lb ai/ac) and at the 1/2×, 1/4×, and 1/8× rates, showing that chlorsulfuron is extremely effective at controlling seedling white sweetclover and could be used for that purpose at lower-than-recommended doses. DMA in 2,4-D treatments did not differ between the 1× (1,600 g ai/ha; 1.4 lb ai/ac) and 1/4× rates in experiment 1 or between the 1/2× and 1/4× rates in experiment 2. Clopyralid reduced DMA below the control down to 1/16 of the recommended rate in both experiments. There was no difference in DMA between the 1× (210 g ai/ha; 0.18 lb ai/ac) and 1/4× rates in experiment 1 or between the 1/2× and 1/8× rates in experiment 2, showing that clopyralid possibly could be effective in controlling seedling white sweetclover biomass at reduced rates. Triclopyr reduced DMA below the control at rates down to 1/8 of the recommended rate (1,260 g ai/ha; 1.11 lb ai/ac) in experiment 1 and down to 1/16× in experiment 2. There was no significant difference in DMA between triclopyr at 1× and 1/2× rates in experiment 1 or between 1/2× and 1/4× rates in experiment 2. The dicamba–diflufenzopyr mixture decreased DMA below the control down to the 1/8× rate in both experiments. DMA was not different between the 1× and 1/2× rates in experiment 1 or between the 1/2× and 1/4× rates in experiment 2. However, because diflufenzopyr is not currently registered for use in Alaska, we did not evaluate the dicamba–diflufenzopyr mixture in field trials. In experiment 1, the 2,4-DB rates to 1/4× slightly reduced seedling white sweetclover DMA; however, in experiment 2, none of the 2,4-DB rates decreased DMA below the control. 2,4-DB was not as effective as the other herbicides at decreasing seedling white sweetclover DMA and was also eliminated from consideration for field evaluation.

Several herbicides, including metribuzin, triallate, and trifluralin, have exhibited increased soil longevity under Alaska conditions (Conn et al. 1996). Using lower-than-recommended herbicide doses could help alleviate problems associated with lengthened herbicide half-lives (Seefeldt et al. 2007). Chlorsulfuron, clopyralid, triclopyr, and 2,4-D appear to hold promise for controlling seedling white sweetclover at rates below recommended rates.

Field Studies. Biomass did not exhibit a treatment by year interaction. Sweetclover biomass was decreased below the control by triclopyr and 2,4-D at recommended rates (1,260 and 1,600 g ai/ha) and by chlorsulfuron at recommended (17.6 g ai/ha) and at the 1/2× and 1/4× rates (Table 2). There was a treatment by year interaction for visual percentage of control and for viable seed production. In 2006, only chlorsulfuron at all rates and triclopyr at the recommended rate (1,260 g ai/ha) produced > 70% visual control of white sweetclover. In 2007, recommended (1×) rates of clopyralid and 2,4-D controlled more than 70% of white sweetclover (Table 2). Sweetclover viable seed production was decreased by chlorsulfuron (at all rates) and by clopyralid, triclopyr, and 2,4-D at recommended (1×) rates in 2006. In 2007, all herbicide treatments, except 2,4-D at the 1/2× rate (800 g ai/ha; 0.71 lb ai/ac), decreased viable seed production. However, only chlorsulfuron at 17.6 g ai/ha eliminated viable seed production altogether. The differences between years in the efficacy of herbicides may be related to precipitation and plant water stress. In 2006, total precipitation from the date of spraying to September 1 was 113 mm (4.4 in), whereas in 2007, it was 33% more (150 mm; 5.9 in).

Flaming and Cutting Studies. Flaming and cutting had similar effects on white sweetclover density and viable seed production in 2004 and 2005, so data were pooled for analysis. Density of first-year white sweetclover was lower in flamed plots than in control plots; however, cutting first-year white sweetclover, at either 2.5 or 10 cm, did not decrease the end-of-season density (Figure 1). Flamed first-year white sweetclover wilted immediately after the treatment and did not recover, whereas cut first-year plants sent out new branches from meristems located at leaf axils below the cut. Second-year white sweetclover density was lower than the control after flaming or cutting at 2.5 cm. There was no reduction in second-year sweetclover density from cutting at 10 cm. The leaves of second-year plants are more widely spaced on the stem than on first-year plants. When plants were cut at 2.5 cm, many of the second-year plants were cut below their lowest leaf axil and meristem and failed to produce new stems. When second-year plants were cut at 10 cm, most plants resprouted with new shoots growing from meristems located below the cut.

No viable seeds were produced by first-year plants in plots that were flamed (Figure 2) because all first-year plants were killed by flaming. First-year plants that were cut at 2.5 cm produced significantly fewer viable seeds (181 seeds/m^2; 17 seeds/ft^2) than first-year plants in the control plots (18,635 seeds/m^2; 1,730 seeds/ft^2). Total viable seed production (first-year + second-year plants) was decreased below the control (35,450 seeds/m^2; 3,293 seeds/ft^2) by both flaming (1,024 seeds/m^2; 95 seeds/ft^2) and cutting at 2.5 cm (266 seeds/m^2; 25 seeds/ft^2). Total viable seed production in plots where white sweetclover was cut at 10 cm (4,819 seeds/m^2; 448 seeds/ft^2) was not different from the control.

Particular white sweetclover populations and associated ecosystems may be better suited to some weed control methods than others. White sweetclover may occur as even-aged stands of either all first-year or all second-year plants or as a mixture of both age classes (Turkington 1978). Using flaming or the herbicides chlorsulfuron, clopyralid, triclopyr, and 2,4-D (perhaps at reduced rates when plants are seedlings) should work well on even-aged, first-year white sweetclover populations. Cutting was not effective at killing or preventing viable seed production by first-year

Table 2. Effects of herbicides at three rates on white sweetclover biomass, percent control, and viable seed production in Fairbanks, AK, in 2006 to 2007.

Herbicide treatment	Rate	Biomass[a]	Control[b]		Viable seed produced[b]	
			2006	2007	2006	2007
	g ai/ha	g/m^2	%		seeds/m^2	
Chlorsulfuron 1/4×	4.4	86[c] bcd	73 bc	100 a	92d	6 c
Chlorsulfuron 1/2×	8.8	74 bc	90 ab	100 a	1e	11 bc
Chlorsulfuron 1×	17.6	72 e	98 a	100 a	0e	0 c
Clopyralid 1/4×	53	140 a	8 gh	30 d	6276 a	130 bc
Clopyralid 1/2×	105	135 ab	10 fg	67 bc	2,644 abc	62 bc
Clopyralid 1×	210	151 ab	35 ef	93 ab	1,145 bc	0 c
Triclopyr 1/4×	320	135 abc	18 fg	77 bc	6,579 a	126 bc
Triclopyr 1/2×	630	76 abc	28 efg	100 a	1,593 abc	0 c
Triclopyr 1×	1260	66 cde	75 bc	100 a	336 c	0 c
2,4-D 1/4×	400	112 abc	20 efg	50 cd	5,015 ab	396 bc
2,4-D 1/2×	800	77 abc	42 de	72 bc	2,765 abc	622 ab
2,4-D 1×	1600	37 de	65 cd	100 a	454 c	0 c
Untreated control	—	123 a	0 h	0 e	9199 a	2,079 a

[a] Biomass ANOVA showed no significant year by treatment interaction, so 2006 and 2007 were combined for statistical analysis.

[b] Percentage of control and viable seed production ANOVAs showed significant year by treatment interactions, so 2006 and 2007 were analyzed separately.

[c] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

plants. For even-aged stands of second-year plants, flaming or cutting at 2.5 cm or applications of clopyralid, triclopyr, or 2,4-D, at recommended rates, should reduce populations, but some plants will still produce seeds unless surviving plants can be removed through subsequent treatment. Chlorsulfuron at the recommended rate was the only treatment eliminating viable seed production by mixed-age populations of white sweetclover. For mixed-age white sweetclover stands, cutting does not seem to be an effective treatment for killing plants or for preventing seed production because it is ineffective for first-year plants.

Each of the treatments evaluated for control of white sweetclover can be expected to have different effects on nontarget species and may be more or less appropriate in different ecosystems where white sweetclover grows. For

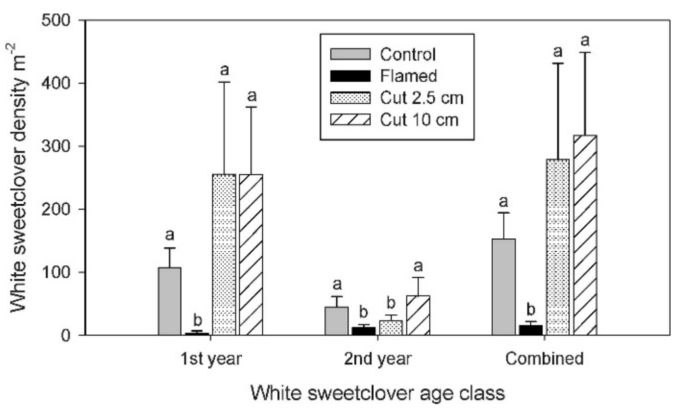

Figure 1. The effect of flaming and cutting at 2.5 and 10 cm above the soil surface on the density of first-year, second-year, and combined-age classes of white sweetclover at Nenana River, AK, in 2004 to 2005. Values are means (+ SE; $n = 7$). Bars within age classes with the same mean separation are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

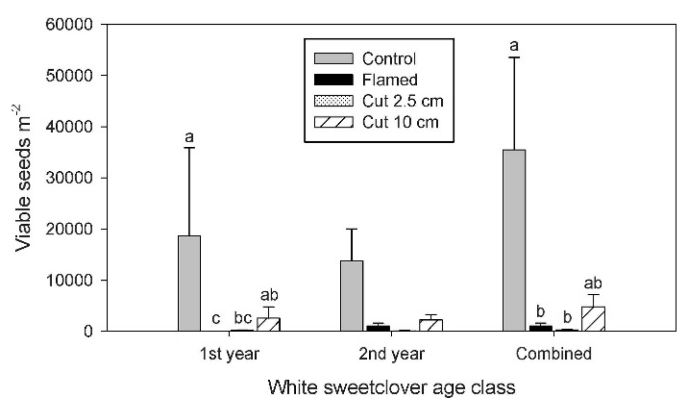

Figure 2. The effect of flaming and cutting at 2.5 and 10 cm above the soil surface on viable seed production of first-year, second-year, and combined-age classes of white sweetclover at Nenana River, AK, in 2004 to 2005. Bars within age classes with the same mean separation are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

example, repeated prescribed burning has been used to control white sweetclover in the prairies of the midwestern United States (Kline 1984). There, fuel loads are sufficient to support prescribed burns at frequent intervals, and prairie species have evolved under conditions of short fire cycles (DiTomaso et al. 2006). However, in Alaska, white sweetclover colonizes early successional environments on floodplains or roadsides, where fuel loads are too low to sustain burning and where the native species are not adapted to fire. Flaming is costly and time consuming, so it may be practical only for control of small populations of first-year white sweetclover in Alaska. Cutting and mowing treatments may have similar negative effects on native species. During cutting of sweetclover in our plots, we found it was difficult to avoid damaging the native vegetation. If cutting was conducted on a bigger scale with larger equipment, substantial damage to native vegetation could occur. It is well known that herbicides affect plant species differently, and their use often results in plant community composition shifts (Haas and Streibig 1982). Long-term studies of the plant-community effects of various weed control methods for white sweetclover control are needed, especially in Alaska.

An integrated approach using a range of herbicides as well as nonchemical means for control of white sweetclover may be the most effective in the long term. Relying on a single approach, such as repeated applications of chlorsulfuron, could result in selection of white sweetclover populations that are resistant to chlorsulfuron and other acetolactate synthase–inhibiting herbicides. In addition, applying herbicides at low rates can select for weed biotypes that have enhanced ability to metabolize the herbicide (Neve and Powles 2005). Alternating or tank-mixing herbicides with different modes of action or with nonchemical control can minimize the chances of developing herbicide resistance (Diggle et al. 2003). Nonchemical weed control methods can control herbicide-resistant plants that may be selected by herbicide treatments (Prather et al. 2000).

Sources of Materials

[1] Sterilized potting soil, Ann's Greenhouses, 780 Sheep Creek Rd, Fairbanks, AK 99709.

[2] Artificial potting mix, Premier Horticulture Incorporated, 127 South 5th Street, No. 300, Quaker Town, PA 18951.

[3] Variable-rate, log-step sprayer, R&D Sprayers, 419 Highway 104, Opelousas, LA 70570.

[4] 8002 VS flat-fan nozzle, Tee-Jet Spraying Systems Co., Wheaton, IL 60187.

[5] Model VT 21/2-30C propane torch, Flame Engineering, Inc., P.O. Box 577, LaCross, KS 67548.

[6] Model T/C/X230 gas-powered lawn trimmer, Shindaiwa, Inc., 11975 SW Herman Rd. Tualatin, OR 97062-8082.

[7] Statistical software, Version 9.1, SAS Institute, Inc., 100 SAS Campus Drive, Cary, NC 27512-2414.

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