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Seed Germination and Seedling Emergence of Scotch Broom (*Cytisus scoparius*)

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Scotch broom is a large, leguminous shrub that has invaded 27 U.S. states. The species produces seeds with a hard coat that remain viable in the soil for years. Growth-chamber studies were conducted to determine effects of temperature regime and cold-stratification period on seed germination. Seedling emergence, mortality, and biomass also were studied in response to sulfometuron and metsulfuron herbicides and variation in soil texture and watering regime. Germination was greatest for a dark/light temperature regime of 15/20 C. Initial rates of germination increased as stratification period was varied from 0 to 60 d, but final germination after 90 d did not differ significantly among periods. Applied alone or in combination, sulfometuron and metsulfuron decreased biomass and increased mortality of seedlings. Mortality from simulated soil drought was greater in the presence versus absence of sulfometuron (20 and 6% mortality, respectively) probably because the herbicide reduced root biomass by 58 to 95%. Invasiveness of Scotch broom is facilitated by a prolonged period of germination across a broad temperature range. Increased control of Scotch broom seedlings with sulfometuron is likely if application is timed to expose recently emerged seedlings to developing conditions of soil drought.
Nomenclature: Metsulfuron; sulfometuron; Scotch broom, *Cytisus scoparius* (L.) Link CYSC4.
Key words: Temperature, stratification, soil texture, watering regime, metsulfuron, sulfometuron.

Scotch broom is a large, leguminous shrub that has invaded 20 eastern and 7 western U.S. states (U.S. Department of Agriculture Natural Resources Conservation Service [USDA NRCS] 2009). A native to the Mediterranean, the species was first introduced in California in the 1850s as an ornamental (Gilkey 1957). Scotch broom seedlings grow vigorously to form dense stands quickly, excluding native plants and altering community structure of prairies, woodlands, and young forests (Bossard and Rejmánek 1994; Wearne and Morgan 2004). Although Scotch broom typically invades roadsides and other areas of soil disturbance, it has the potential to establish and survive in conditions of low light availability (10% of full sun; Williams 1981), such as those of a forest understory (Harrington 2007). Scotch broom is a prolific seed producer with individual shrubs producing an average of 9,650 viable seeds per year (Bossard and Rejmánek 1994). Once buried, seeds are capable of germinating from depths of 1 to 6 cm (Bossard 1993; Williams 1981). Seeds have an impervious coat that prevents germination (Young and Young 1992), but rapid alternating immersion in boiling water and liquid nitrogen dramatically improved germination 3.5-fold (Abdallah et al. 1989). Bossard (1993) found that some seeds germinated without further treatment when kept moist at temperatures of 5 to 18 C ($\leq$ 23% of seeds sown); however, addition of the pregermination treatment of Abdallah et al. (1989) resulted in germination rates of 60 to 98%. Seeds buried in the soil had delayed germination for at least 5 yr, enabling development of a large seed bank (Bossard 1993; Bossard and Rejmánek 1994). In Australia, seed banks were estimated to store from 4,000 to 21,000 seeds m^{-2} (Sheppard et al. 2002).

Scotch broom is considered a noxious weed in California, Hawaii, Idaho, Oregon, and Washington. Tactics for controlling Scotch broom in forest and rangelands include cutting, prescribed fire, and herbicide treatments. Manual cutting of broom in August prevented sprouting on greater than 90% of shrubs (Bossard and Rejmánek 1994). Individual foliar applications of clopyralid, fluroxypyr, and triclopyr herbicides reduced Scotch broom cover to 10% or less by 40 wk after treatment (Blair and Zedaker 2005). Preemergent (PRE) applications of hexazinone and metsulfuron herbicides were effective at reducing survival of emerging seedlings; however, applications of sulfometuron herbicide reduced leaf development and biomass of seedlings but did not affect their survival (Ketchum and Rose 2003). Those authors speculated that stunted development of Scotch broom seedlings from sulfometuron would render them more vulnerable to mortality from soil drought—conditions typical of summer in the Mediterranean climate of the Pacific Northwest.

To improve understanding of Scotch broom invasibility in the Pacific Northwest, growth-chamber studies were conducted to determine effects of temperature regime and cold-stratification period on seed germination. Seedling emergence, mortality, and biomass responses also were studied to identify potential interactions of the soil-active herbicides, sulfometuron and metsulfuron, with soil texture and watering regime. The research included testing the null hypothesis that seedling mortality from soil drought was not affected by PRE application of sulfometuron.

Materials and Methods

Seed Sources. Scotch broom seeds were collected annually in 2004 to 2006 from the Olympia and Matlock, WA, areas. Collections were made beginning in mid-July, as soon as seed pods began to dehisce, and continued into September. Prior to being removed from their pods, seeds were dried thoroughly at room temperature and then stored in sealed glass containers at 5 C. Seeds from the previous growing season were used in each study.

Temperature Regime. Seed germination was studied from January to March 2005 in five dark/light (14/10 h) temperature regimes: 5/10, 10/15, 15/20, 20/25, and 25/30 C. Seeds were counted into 15 samples of 100 each, imbibed by soaking each sample for 24 h in deionized water, and cold stratified for 45 d at 5 C. Seeds were then placed on moistened paper trays in covered Petri dishes, and the dishes

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were placed in a controlled-environment growth chamber[1] with daytime light conditions averaging 87 μmole m^{-2} s^{-1} photosynthetic photon flux density (PPFD). Germination was recorded when the hypocotyl had elongated at least 2 mm. Germination counts were conducted daily for 24 d after sowing, and paper trays were remoistened with 1 to 2 ml of deionized water at each count. The experimental design is completely randomized with three replications of the five temperature regimes.

Stratification Period. Seed germination was studied from May to July 2005 after five cold-stratification periods: 0, 15, 30, 45, and 60 d. Seeds were counted into 15 samples of 100 each. Methods for imbibing and stratifying seeds were identical to those of the temperature study except where noted. The dark/light temperature regime (14/10 h) was 15/20 C—the optimum regime identified in the temperature study. Germination counts were conducted through 90 d after sowing. Count frequency was every day during the first 45 d and every other day thereafter. The experimental design is completely randomized with three replications of the five stratification periods.

Herbicides and Soil Texture. Seedling emergence, mortality, and biomass responses to two herbicides were studied from February to May 2006 after seed was sown in clear plastic containers (dimensions: 12 cm long by 17 cm wide by 6 cm deep) filled with forest soils of contrasting texture. The first soil, collected at a site near Matlock, WA (47.206°N, 123.442°W), is a very gravelly loamy sand of the Grove series (Dystric Xerorthent) formed in glacial outwash. The second soil, collected at a site near Molalla, OR (45.196°N, 122.285°W), is a cobbly loam of the Kinney series (Andic Dystrudept). Each soil was sieved to remove coarse fragments greater than 2 mm. Fifteen containers were filled with a fixed weight of dry soil from each source, soil was tamped level, resulting in a 3-cm depth, and deionized water was applied to achieve field capacity based on measured weight (volumetric moisture contents of 35 and 50% for Grove and Kinney soil series, respectively). Results of the stratification study indicated nonsignificant (NS) effects of stratification period on final germination of Scotch broom seed; therefore, nonstratified seeds were used in this study. Samples of 50 seeds each were spread across the soil surface of each container and seeds were pressed in to the minimum depth that completely covered them with soil. Each of the following herbicide treatments was randomly assigned to three containers per soil type:

1. Nontreated check (water only)
2. Sulfometuron (0.16 kg ai ha^{-1})
3. Metsulfuron (0.04 kg ai ha^{-1})
4. Sulfometuron (0.08 kg ai ha^{-1}) + metsulfuron (0.02 kg ai ha^{-1})
5. Sulfometuron (0.16 kg ai ha^{-1}) + metsulfuron (0.04 kg ai ha^{-1})

These herbicide rates are commonly used on forest land for PRE control of herbaceous vegetation that competes with newly planted seedlings of coast Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*]. All treatments were applied in deionized water via an adjustable pipetor[2] to achieve an equivalent spray volume of 1,870 L ha^{-1}. This high spray volume—three to six times that recommended on the product label for aerial and ground applications—was used to increase uniformity of herbicide distribution within the container. Containers were placed in a controlled-environment growth chamber[3] with light conditions of approximately 50 μmole m^{-2} s^{-1} PPFD and a dark/light temperature regime (14 h/10 h) of 15/20 C. Soils were watered uniformly with deionized water periodically during the study. Emergence was recorded when the epicotyl had elongated at least 2 mm. Emergence and mortality counts were conducted through 90 d after sowing. Count frequency was every day during the first 45 d and every 2 to 3 d thereafter. At the end of the study, living seedlings from each container were removed, separated into shoot and root components pooled by container, and dried in a forced-draft oven at 65 C to a constant weight. The experimental design is completely randomized with three replications of 10 treatments arranged as a factorial of the five herbicide treatments and two soil textures.

Sulfometuron and Watering Regime. Seedling emergence, mortality, and biomass responses to sulfometuron level and contrasting watering regimes were studied from January to April 2007. Study methods were identical to those of the herbicides and soil texture study except where noted. The following treatments were randomly assigned to three containers per soil texture:

1. No sulfometuron + H/L: watering applied at a high rate for 46 d then at a low rate for 44 d.
2. No sulfometuron + L/H: watering applied at a low rate for 46 d then at a high rate for 44 d.
3. Sulfometuron (0.16 kg ai ha^{-1}) + H/L.
4. Sulfometuron (0.16 kg ai ha^{-1}) + L/H.

Container dimensions were 11 cm long by 11 cm wide by 3 cm deep. To initiate germination, soils for both watering regimes were kept at field capacity (35 and 50% volumetric moisture contents for Grove and Kinney soil series, respectively) until the ninth day after sowing the seeds. The high-rate watering treatment required applying the volume of deionized water each day sufficient to replace water loss from evapotranspiration (10 ml), thereby maintaining field capacity based on measured weight. Daily application of water in the low-rate watering treatment was half the volume of the high rate (5 ml). By day 17, soils in the high-rate water treatment had 40 ml more water than those in the low-rate treatment, and this difference was maintained by daily additions of water based on container weight. After day 46, watering rates were switched to create H/L and L/H watering regimes (application of 5 and 10 ml per d, respectively), imposing conditions of soil drought and rehydration, respectively. This watering rate was maintained until a 40-ml difference in water volume existed between treatments, after which the difference was maintained until study termination (day 90). The experimental design is completely randomized with three replications of eight treatments arranged as a factorial of the two sulfometuron levels, two soil textures, and two watering regimes.

Statistical Analysis. All statistical analyses were conducted in SAS[4] with a significance level of $\alpha = 0.05$. For each sample of

Table 1. Effects of temperature regime and stratification period on Scotch broom germination. Germination was studied for 24 d in the temperature regime study and for 90 d in the stratification period study. Means for a given factor and variable followed by the same letter do not differ significantly (P > 0.05).

				Weibull model parameters[a]		
Factor	Level	Germination	T_{50}[b]	z	k	c
		%	d	d		
Temperature regime[c]	5/10 C	16 c	105 a	2.5 a	0.005 a	0.87 a
	10/15 C	25 b	49 b	1.8 a	0.015 a	1.14 a
	15/20 C	41 a	39 b	2.1 a	0.017 a	0.72 a
	20/25 C	33 ab	54 ab	2.9 a	0.007 a	0.48 a
	25/30 C	4 d	49 ab	0.4 a	0.007 a	1.62 a
Stratification period (d)	0	48 a	76 b	6.0 a	0.009 a	0.71 ab
	15	52 a	81 ab	5.3 a	0.008 ab	0.75 a
	30	52 a	89 ab	3.9 ab	0.007 abc	0.61 ab
	45	52 a	97 ab	3.3 ab	0.005 bc	0.45 ab
	60	54 a	134 a	0.0 b	0.003 c	0.44 b

[a] z is lag time, k is rate, and c is the shape parameter in the Weibull model for germination.
[b] T_{50} is the projected number of days to achieve 50% germination.
[c] Temperature regimes refer to 14 h dark and 10 h light periods.

Scotch broom seed (n = 50 or 100 seeds), a Weibull cumulative density function (Larsen and Bibby 2005) was fitted to the values of cumulative germination or emergence (Y) with the use of PROC NLIN:

$$Y = 1 - \exp(-[k(t-z)])^c, \qquad [1]$$

where k is the rate parameter, t is time (d) since sowing, z is lag time (d) until initiation of germination or emergence, and c is the shape parameter. This model form, which assumes that potential germination or emergence equals 100%, was selected because it required estimating only three parameters, yet it fit the data remarkably well based on scatterplots of residual versus predicted values. The projected time (d) of germination or emergence of 50% of the population (T_{50}) was calculated from the Weibull parameter estimates as follows (Larsen and Bibby 2005):

$$T_{50} = z + (1/k)\left(\log_e(100/(100-50))\right)^{1/c}, \qquad [2]$$

where parameters are the same as those defined for Equation 1. In the sulfometuron and watering regime study, seedling emergence could not be characterized by the Weibull function because responses changed dramatically after reversal of the watering rates. Each of the following variables was subjected to ANOVA in PROC GLM: Weibull parameters k, z, c; T_{50}; final germination, emergence, and mortality; and total shoot and root biomass. The proportionate variables, germination and emergence, were subjected to an arcsine, square-root transformation prior to ANOVA to homogenize their residual variances (Sokal and Rohlf 1981, pp. 427–428). If main effects of a given treatment were significant, Tukey's honestly significant difference (HSD) test was used to perform multiple comparisons of adjusted treatment means with Bonferroni-adjusted probabilities to control Type I error rates (Quinn and Keough 2002). If a factor interaction was significant, multiple comparisons were conducted similarly on the simple main effects (i.e., means were compared among levels of one factor while holding other factors constant).

Results and Discussion

Temperature Regime. Cumulative germination of Scotch broom seeds at 24 d was greatest in the 15/20 C temperature regime (41%), but it did not differ significantly (P = 0.238) from that of the 20/25 C regime (33%) (Table 1). Only 4% of seeds germinated in the warmest regime (25/30 C), whereas 16% germinated in the coolest regime (5/10 C). These results are in general agreement with those of Bossard (1993), in which cumulative germination of Scotch broom seeds after 27 d was greatest at temperatures of 22 C or 26 C (32% and 35% germination, respectively) and least at temperatures of 30 or 33 C (6% and 2%, respectively). Projected days until 50% germination (T_{50}) did not differ significantly among temperature regimes warmer than the 5/10 C treatment (P = 1.00), ranging from 39 to 54 d. Although none of the Weibull model parameters differed significantly among temperature regimes (P > 0.155), the fitted curves described a broad range of treatment responses (Figure 1). The relatively short duration of this study (24 d) may have limited detection of treatment effects on the Weibull parameter estimates.

Stratification Period. Seed germination of Scotch broom was active throughout the duration of the stratification study (90 d). The shape of the germination curves during the first

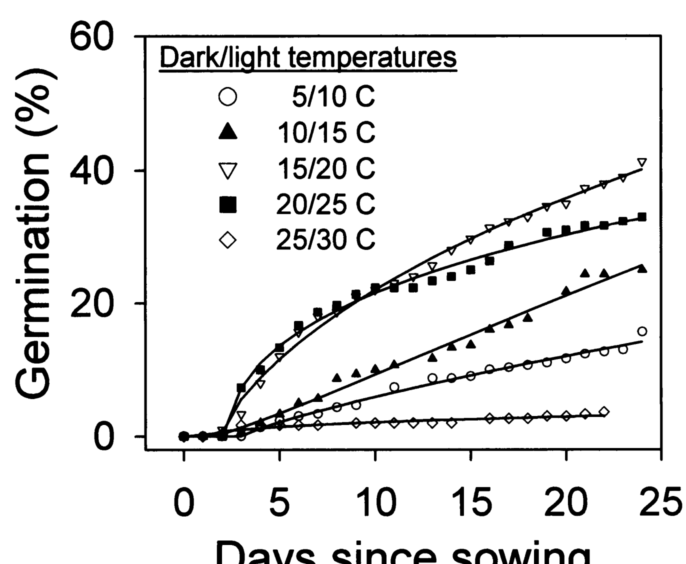

Figure 1. Seed germination of Scotch broom in various dark/light temperature regimes. Plotted curves illustrate the relative fit of the Weibull models.

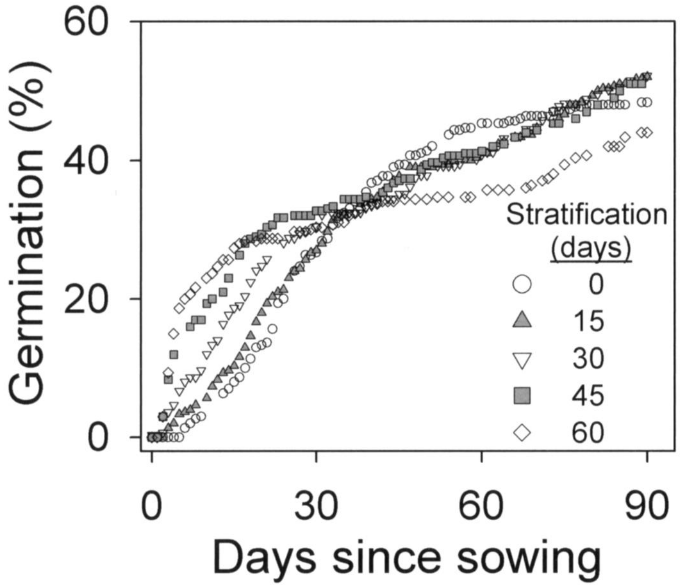

Figure 2. Seed germination of Scotch broom after various cold-stratification periods.

20 d after sowing ranged from concave with respect to *y*-axis (0 to 15 d stratification) to linear (30 d stratification) to concave with respect to the *x*-axis (45 to 60 d stratification) (Figure 2). Although initial rates of germination varied substantially among stratification periods, cumulative germination at 90 d did not differ significantly (P = 0.643) and varied from 48 to 54% (Table 1). In the absence of stratification, T_{50} averaged 57% of that observed after 60 d of stratification, suggesting that prolonged stratification delayed or prevented germination of some of the seeds within the population. Germination initiated immediately without any lag time after 60 d of stratification (i.e., Weibull *z* parameter = 0). However, with 0 to 15 d of stratification, seeds took 5 to 6 d to initiate germination. Both the Weibull rate (*k*) and shape (*c*) parameters decreased with increasing stratification period.

Although identical conditions existed for specific treatments of the temperature and stratification studies (i.e., 15/20 C temperature regime and 45 d stratification), cumulative germination differed nonsignificantly between the two studies at day 24 (means with 95% confidence intervals: 41 ± 10% versus 32 ± 11%, respectively). Seeds for both studies were collected in July 2004, but initiation of the 15/20 C treatment of the temperature study (January 14, 2005) occurred almost 6 mo earlier than initiation of the 45-d treatment of the stratification study (July 4, 2005), indicating less time in cold storage. Bossard (1993) observed a similar, nonsignificant difference in cumulative germination between fresh seeds and those that had been stored for 11 mo (50 versus 34%, respectively).

Herbicides and Soil Texture. Seedling emergence of Scotch broom at 90 d did not differ significantly among herbicide treatments (P = 0.468) or soil textures (P = 0.513), ranging from 62 to 70% (Table 2). Projected days until 50% emergence (T_{50}) also did not differ significantly among herbicide treatments (P = 0.607) or soil textures (P = 0.133). However, seedling mortality was greater (P ≤ 0.032) after each of the herbicide treatments (5 to 9%) than in the nontreated check (< 1%) (Figure 3). Mortality also was greater (P = 0.013) in the gravelly loamy sand (7%) than in the cobbly loam (4%). The lag time for germination (Weibull *z* parameter) and the Weibull *k* and *c* parameters did not differ significantly among herbicide treatments or soil textures (P ≥ 0.085). Shoot biomass of Scotch broom seedlings in the various herbicide treatments averaged 58 to 83% of that in the nontreated check (Table 3). However, root biomass of seedlings in the full-rate sulfometuron treatment (Treatment 2) was only 32% of that in the nontreated check. The other herbicide treatments reduced root biomass by half or more. Root biomass in the gravelly loamy sand averaged 60% of that in the cobbly loam. The interaction of herbicide treatment and soil texture was not significant for any variable (P ≥ 0.100).

Sulfometuron and Watering Regime. Seedling emergence of Scotch broom approximately doubled within 8 d after watering was switched from a low rate to a high rate in the L/H watering regime, regardless of presence or absence of sulfometuron (Figure 4). Conversely, mortality increased dramatically after watering rate was switched from a high rate to a low rate in the H/L watering regime, especially in the presence of sulfometuron. Seedling emergence at 90 d did not differ significantly between sulfometuron levels or soil textures (P ≥ 0.149), but it was greater in the L/H watering regime (43%) than in the H/L watering regime (34%) (P = 0.018; Table 4). Seedling mortality at 90 d varied as a result of the

Table 2. Main effects of herbicide treatment and soil texture on Scotch broom 90 d emergence and mortality. Means for a given factor and variable followed by the same letter do not differ significantly (P > 0.05).

Factor	Type	90 d emergence	T_{50}[b]	Mortality	Weibull model parameters[a] *z*	*k*	*c*
		%	d	%	d		
Herbicide treatment[c]	Nontreated check	69 a	53 a	0.5 b	2.4 a	0.014 a	1.07 a
	Sulfometuron (0.16)	63 a	61 a	7.5 a	3.9 a	0.013 a	0.96 a
	Metsulfuron (0.04)	70 a	60 a	6.9 a	3.9 a	0.012 a	1.04 a
	Sulfometuron + metsulfuron (0.08 + 0.02)	68 a	53 a	5.1 a	3.0 a	0.015 a	1.09 a
	Sulfometuron + metsulfuron (0.16 + 0.04)	62 a	66 a	8.5 a	4.1 a	0.012 a	0.81 a
Soil texture	Gravelly loamy sand	67 a	54 a	7.0 a	4.2 a	0.014 a	0.94 a
	Cobbly loam	65 a	63 a	3.5 b	2.7 a	0.012 a	1.05 a

[a] *z* is lag time, *k* is rate, and *c* is the shape parameter in the Weibull model for emergence.
[b] T_{50} is the projected number of days to achieve 50% emergence.
[c] The rate of application (kg ai ha^{-1}) for each herbicide is given in parentheses.

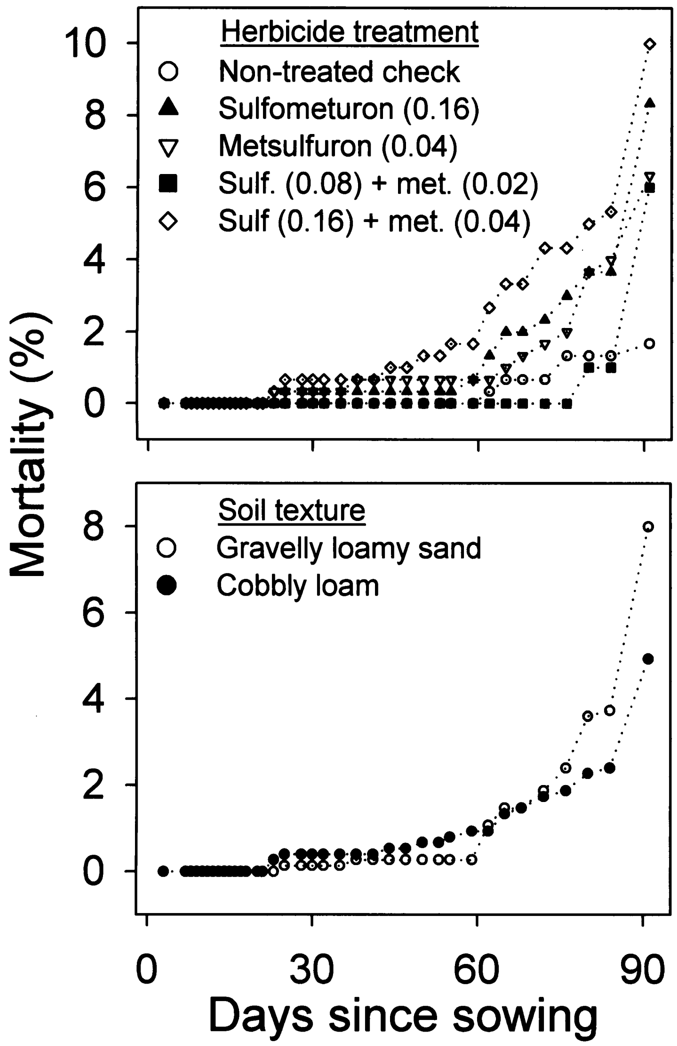

Figure 3. Seedling mortality of Scotch broom as affected by main effects of four PRE herbicide treatments (upper graph) and two soil textures (lower graph). Application rates (kg ai ha^{-1}) for each herbicide are given in parentheses.

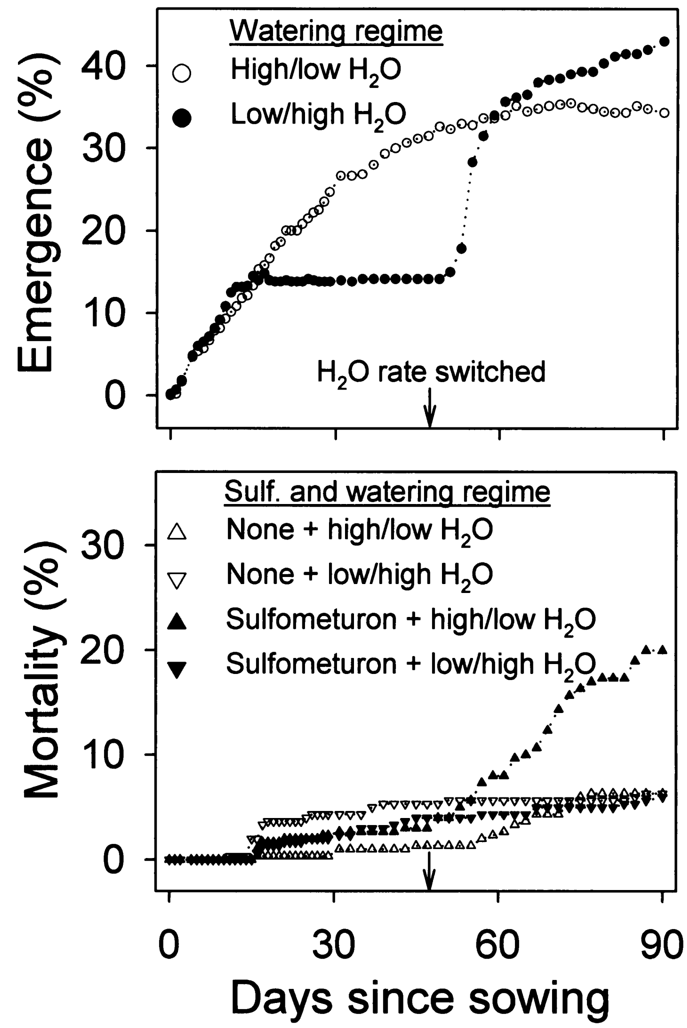

Figure 4. Seedling emergence (upper graph) and mortality (lower graph) of Scotch broom as affected by two watering regimes in the presence (0.16 kg ai ha^{-1}) versus absence (0 kg ai ha^{-1}) of sulfometuron applied as a PRE treatment. Sulfometuron did not affect emergence ($P = 0.845$); therefore, only main effects of watering regime are shown for this variable.

interaction of sulfometuron level and watering regime ($P = 0.011$). In the presence of sulfometuron and the H/L watering regime, mortality (20%) was three to four times that observed in the other treatments (5 to 6%). Conversely, in the L/H watering regime, mortality did not differ in the presence versus absence of sulfometuron. Shoot and root biomass each varied as a result of a three-way interaction of sulfometuron level, soil texture, and watering regime ($P \leq 0.020$). Biomass differed most between presence and absence of sulfometuron for the H/L watering regime, particularly for the gravelly loamy sand, where the herbicide reduced shoot and root

Table 3. Main effects of herbicide treatment and soil texture on biomass of Scotch broom seedlings. Means for a given factor followed by the same letter do not differ significantly ($P > 0.05$).

Factor	Type	Biomass	
		Shoot	Root
		g	
Herbicide treatment[a]	Nontreated check	0.41 a	0.57 a
	Sulfometuron (0.16)	0.31 ab	0.18 b
	Metsulfuron (0.04)	0.33 ab	0.26 b
	Sulfuron + metselfuron (0.08 + 0.02)	0.34 ab	0.31 b
	Sulfuron + metselfuron (0.16 + 0.04)	0.26 b	0.20 b
Soil texture	Gravelly loamy sand	0.30 a	0.23 b
	Cobbly loam	0.35 a	0.38 a

[a] The rate of application (kg ai ha^{-1}) for each herbicide is given in parentheses.

Table 4. Effects of sulfometuron level, soil texture, and watering regime on Scotch broom emergence and mortality. Means for a given factor or factor interaction followed by the same letter do not differ significantly ($P > 0.05$).

Factor	Type	Emergence	Mortality
		%	
Sulfometuron level[a]	Absent	38 a	5.3 b
	Present	39 a	11.8 a
Soil texture	Gravelly loamy sand	41 a	10.2 a
	Cobbly loam	36 a	6.5 a
Watering regime[b]	H/L	34 b	11.9 a
	L/H	43 a	5.2 b
Sulfometuron level × watering regime	None + H/L	33 a	5.9 b
	None + L/H	43 a	4.8 b
	Sulfometuron + H/L	35 a	19.8 a
	Sulfometuron + L/H	42 a	5.7 b

[a] Sulfometuron levels: absent = 0 kg ai ha^{-1}; present = 0.16 kg ai ha^{-1}.
[b] Watering regimes: H/L = high-then-low rate; L/H = low-then-high rate.

Table 5. Effects of the three-way interaction of sulfometuron level, soil texture, and watering regime on Scotch broom biomass. Means for a given variable followed by the same letter do not differ significantly ($P > 0.05$).

Sulfometuron level[a]	Soil texture[b]	Watering regime[c]	Biomass	
			Shoot	Root
			g	
Absent	GLS	H/L	0.34 a	0.57 a
		L/H	0.22 bc	0.17 bc
	CL	H/L	0.18 bcd	0.26 b
		L/H	0.26 ab	0.25 b
Present	GLS	H/L	0.06 e	0.03 d
		L/H	0.15 cde	0.07 cd
	CL	H/L	0.08 de	0.11 cd
		L/H	0.23 bc	0.16 bc

[a] Sulfometuron levels: absent = 0 kg ai ha^{-1}; present = 0.16 kg ai ha^{-1}.
[b] Soil textures: GLS = gravelly loamy sand; CL = cobbly loam.
[c] Watering regimes: H/L = high-then-low rate; L/H = low-then-high rate.

biomass by 82 and 95%, respectively (Table 5). In contrast, biomass did not differ between presence and absence of sulfometuron for the L/H watering regime, regardless of soil texture. In the presence of sulfometuron, biomass in the H/L watering regime did not differ between soil textures, whereas in the absence of sulfometuron, biomass in the H/L watering regime was greater in the gravelly loamy sand than in the cobbly loam.

Invasiveness of Scotch broom is aided by a prolonged period of germination across a broad range of temperatures. In this research, germination was still underway 90 d after sowing seeds. Bossard (1993) noted that temperature provides little barrier for Scotch broom germination because seeds do not require cold stratification or variable day/night temperatures to germinate. However, this research clearly demonstrates that cold stratification provides an advantage for seedling establishment. Seed populations having 60 d of cold stratification initiated rapid rates of germination without any lag time, whereas those having 0 to 15 d of stratification initiated much slower rates of germination after a 5 to 6–d lag. In the sulfometuron and watering regime study, germination rates rebounded dramatically after soils were rehydrated, suggesting that Scotch broom seeds respond quickly to rewetting of soils after an extended drought. Based on this research, for areas west of the Cascade Mountains in the Pacific Northwest, Scotch broom seeds deposited during summer drought in July will be able to germinate as soon as rains return in September or October, and germination can proceed into December as long as daytime temperatures exceed 10 C.

The soil-active herbicides, sulfometuron and metsulfuron, decreased biomass and increased mortality of Scotch broom seedlings. These data provide clear evidence for rejecting the null hypothesis that seedling mortality from soil drought was not affected by PRE application of sulfometuron. When conditions of soil drought were imposed (H/L watering regime), seedling mortality was over two times greater in the presence versus absence of sulfometuron. Conversely, when soils were rehydrated after a period of drought (L/H watering regime), seedling biomass and mortality did not differ in the presence versus absence of sulfometuron.

Increased control of Scotch broom with sulfometuron is likely if PRE application is timed to expose recently emerged seedlings to developing conditions of soil drought. In the Pacific Northwest, this effect can be achieved if sulfometuron is applied in late April to early May, just prior to the last significant rainfall, because some rainfall is needed to move the herbicide to the soil depth at which seed germination is occurring. The herbicide stunts development of seedlings, particularly their root biomass, by inhibiting biosynthesis of amino acids (Ahrens 1994), and thus renders them vulnerable to mortality from soil drought. Research results also suggest that PRE application of sulfometuron during soil drought will result in limited control of Scotch broom seedlings, even when soils are rehydrated 47 d later.

Sources of Materials

[1] Germinator, Percival Scientific, model E57, Perry, IA.

[2] Pipetor, Oxford Macro-Set Transfer Pipetting System, model 890007 (5 ml capacity), St. Louis, MO.

[3] Germinator, Controlled Environments, model G30, Winnipeg, Manitoba, Canada.

[4] The SAS System for Windows, Version 9.1, 2005, SAS Institute, Cary, NC.

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