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Preventing establishment of exotic shrubs (*Cytisus scoparius* (L.) Link. and *Cytisus striatus* (Hill)) with soil active herbicides (hexazinone, sulfometuron, and metsulfuron)

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Abstract. A greenhouse study was conducted evaluating the potential for commonly used forestry herbicides to control germination success of Scotch broom (*Cytisus scoparius* (L.) Link.) and Portuguese broom (*Cytisus striatus* (Hill). Three herbicides, hexazinone, sulfometuron and metsulfuron, were evaluated at six rates encompassing normal rates used for herbaceous weed control. The data suggest that these herbicides applied prior to establishment can strongly affect seedling establishment of these species even though they are ineffective on mature individuals. Hexazinone strongly affected both the final weight of surviving seedlings and the probability of seedlings from broom species to survive to week nine. Sulfometuron had no effect on survival probability of either species but reduced final dry weight and delayed true leaf development at increased rates. Metsulfuron reduced the survivorship potential of Scotch broom but not Portugese broom. Final dry weight decreased and development of true leaves was delayed for both species treated with metsulfuron. These results suggest that preemergence treatments with hexazinone may provide an effective method of preventing broom establishment. Sulfometuron and metsulfuron were not as effective at preventing successful establishment as hexazinone.

Introduction

Scotch broom (*Cytisus scoparius* (L.) Link.) is an exotic shrub found in disturbed areas along the West Coast from Canada to Northern California (Randall et al. 1994). Two other closely related broom species Portuguese broom (*Cytisus striatus* (Hill.)) and French broom (*Genista monspessulanas* (L.) L. Johnson) are also present in these climes and have the potential to become naturalized. All three broom species are considered Class B noxious weeds in Washington and Oregon (Parker et al. 1994). Class B noxious weeds are of known economic importance and limited to intensive control at the state or county level is recommended on a case-by-case basis. They are commonly found in disturbed areas such as road ways, gravel pits, pastures, and cultivated fields (Dennis 1980). Scotch broom is also commonly associated with young Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.) forests in British Columbia, Washington and Oregon (Peterson and Prasad 1998).

The noxious weed status of Scotch broom makes it a target for control by foresters, rights-of-way workers, and other private or public land managers. In forest plantations, brooms are rapid growing shrubs that compete with crop trees (Zielke et al. 1992; Prasad and Petersen 1997; Peterson and Prasad 1998). They produce abundant seed (Bossard and Rejmanek 1994) that can remain dormant for several years in the soil. Scotch broom circa grow to one meter in height within the first year and to four meters within a few more years (Wilson 1994). Within two years a single plant can produce as many as 2,000 to 2,500 seed pods, each containing multiple seeds (Zielke et al. 1992). Seeds can also be introduced on vehicle tires and in gravel during road building operations prior to and during forest harvesting (Dennis 1980). Once established, infestations can quickly spread into freshly disturbed areas.

Control of established Scotch broom plants can be accomplished using a variety of herbicides (William et al. 1994; Peterson and Prasad 1998). However, the most commonly used herbicides for broom control (2,4-D, glyphosate and triclopyr) can also damage newly planted and established conifers (Conard and Emmingham 1984; Cole et al. 1989; Figeuroa et al. 1990). Rather than treating established broom populations, a better management strategy might be to eliminate the plants before they become well established. In the Pacific Northwest, herbicides such as sulfometuron and metsulfuron are commonly used as fall site preparation treatments prior to winter conifer planting. Similarly, sulfometuron and hexazinone are used as spring release applications soon after planting and provide excellent conifer safety (Cole et al. 1988, 1989). Anecdotal observations suggest these herbicides might also influence the germination of broom species.

The objective of this study was to evaluate the effect of sulfometuron, hexazinone and metsulfuron on emergence and establishment of Scotch broom and Portuguese broom.

Materials and methods

Experimental design

The study consisted of six independent experiments with the same experimental design. Each independent experiment utilized a completely randomized design with 6 sequential rates of a single herbicide tested over one of the broom species. Treatments were replicated 8 times and each replication consisted of six seeds of a single species placed on the surface of a 2 × 3 × 2 inch pot filled with a sandy loam soil. This resulted in 48 (6 rates × 8 replications) pots per single species-herbicide rate combination. The soil used was an amalgamation of top soil purchased from a local gravel pit. Soil analysis found it to have a pH of 6.5, a CEC of 14 meq/100g and 0.81% of C. A thin layer of fine gravel was placed over the seeds to hold them in place during watering. Seeds were scarified prior to planting by nicking the seed coat with a sharp knife and soaking the seed for 12 h in water (Gill and Pogge 1974).

Treatments

The rates of hexazinone, sulfometuron, and metsulfuron ranged from a no herbicide

Table 1. Herbicide rates tested. Rates are given in both metric and english units based on the amount of active ingredient (a.i.). Hexazinone was applied as Velpar L®, Sulfometuron as Oust® and Metsulfuron as Escort®.

Treatment	Hexazinone		Sulfometuron		Metsulfuron	
	kg a.i./ha	oz a.i./ac	kg a.i./ha	oz a.i./ac	kg a.i./ha	oz a.i./ac
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.56	8	0.05	0.75	0.01	0.15
3	1.12	16	0.10	1.50	0.02	0.30
4	1.68	24	0.15	2.25	0.03	0.45
5	2.24	32	0.20	3.00	0.04	0.60
6	3.36	48	0.30	4.50	0.08	1.20

control to nearly double normal operational rates (Table 1). Field operational rates generally fall between that of treatments four and five. The treatments were applied via a backpack gas powered boom sprayer on August 16 1997. Delivery pressure was maintained at 30 psi for all applications. The boom consisted of three equally spaced 8002 flat fan nozzles. All the pots for a given herbicide rate were placed within a 1.86 m^2 area equivalent to 0.000186 h. The calculated amount of herbicide based on this area for each rate was added to a 500 ml solution and the entire solution was sprayed evenly over the designated area. Following the herbicide treatment, pots were moved to a greenhouse and watered three times daily by a light mist irrigation system that kept the pots moist throughout the experiment.

Measurements

The number of live seedlings was recorded twice-weekly following herbicide treatment. Only seedlings with exposed cotyledons were counted. The number of seedlings with true leaves was also recorded at each timing. After nine weeks all the surviving seedlings were counted, harvested and dried for 24 h in an oven at 60 °C. Care was taken to keep the seedlings root systems intact. An average weight of surviving seedlings was determined by dividing the dry weight of harvested seedlings per pot by the number of seedlings that survived until week nine.

Analysis

Binomial logistic regression (PROC GENMOD in SAS 7.0) was used to analyze the number of seedlings that survived the full nine weeks at the differing herbicide rates. Binomial logistic regression was used because of the proportional nature of survivorship data (Ramsey and Schafer 1997). This analysis technique allowed modeling the probability for seedlings to survive to week nine at the different herbicide rates. The proportion of seedlings surviving per pot was the dependent variable and the herbicide rate the independent variable. Independent analyses were run for each species-herbicide combination tested. In addition, linear regression (PROC GLM in SAS 7.0) weighted by number of live seedlings was used to model the average weight of surviving seedlings by herbicide rate at the end of the experiment. A log transformation was required to meet assumptions of equal variance in this analysis and data reported is back-transformed. Finally, the mean number of seedlings to germinate and to develop true leaves at each sampling period was calculated and plotted for each species-herbicide combination.

Results

Hexazinone

The probability for a seedling to survive the entire nine-week study period decreased rapidly with increasing rate of hexazinone for both broom species (Figure 1). At rates greater than 1.68 kg a.i./ha there was less than a 10% chance for a seedling of either species to survive. Average seedling weight of both species was also significantly reduced by increasing hexazinone rate (Figure 1). Herbicide rate accounted for 49% of the variability in final weight of Scotch broom and 25% for Portuguese broom.

Seeds of both species germinated within the first week of planting and the number of seedlings increased rapidly to about day 22 for both species (Figures 2 and 3). At this point the number of living Scotch broom seedlings began to drop quickly at all hexazinone rates. At the end of the nine-week period, few Scotch broom seedlings remained alive in any of the herbicide treatments with exception of the lowest herbicide rates. At the lowest rate an average of one seedling per pot survived. Few seedlings at the higher hexazinone rates developed true leaves primarily due to low survival rate. In the untreated control and the lowest herbicide rate (0.56 kg a.i./ha), nitrogen fixing nodules were present on roots of most Scotch broom individuals, but at the higher rates few nodules were present (data not shown).

For Portuguese broom, seedling survival dropped quickly and was near zero by the end of the study for treatments 3 (1.12 kg a.i./ha), 5 (2.24 kg a.i./ha), and 6 (3.36 kg a.i. kg/ha) (Figure 3). Treatments 2 (0.56 kg a.i./ha) and 4 (1.68 kg a.i./ha) had little effect on seedling survival. At the two lower rates most surviving seedlings eventually developed true leaves before nine weeks, but the seedlings were smaller than in the untreated control plants. Nodulation did not appear to be affected by herbicide rate for Portuguese broom.

Sulfometuron

The probability of seeds of either species to germinate and survive to day 60 was not significantly affected by sulfometuron rate (Figure 1). In contrast, increasing sulfometuron rate significantly reduced average seedling weight for both species. However, variability accounted for by the regression model was less than 30% for either species. Seedling weight decreased nearly linearly with increased herbicide rate.

Seedling development was similar for both broom species. In general, the greater the sulfometuron rate the longer the delay in development of true leaves. Seedling numbers increased rapidly over the first two weeks (50% of planted seed) and did not significantly change thereafter throughout the duration of the study (Figures 2

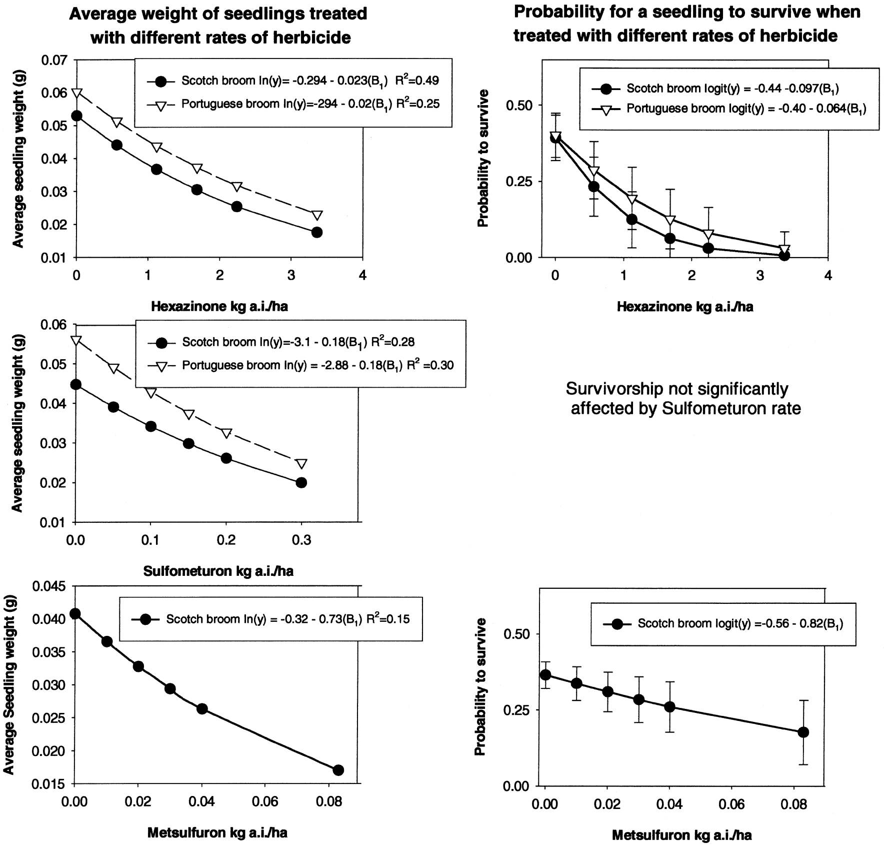

Figure 1. Regression curves for average weight of seedlings of both species (Scotch broom and Portuguese broom) are illustrated for different rates of the three herbicides examined (back transformed from a Ln transformation). In addition, curves generated for the probability of a seedling to survive when treated with different rates of herbicide are illustrated by herbicide examined (back transformed from a logit transformation). Error bars represent standard errors, and curves for only those species whose probability for survival was significantly influenced by the herbicide in tests are shown.

and 3). Sulfometuron applications delayed the development of true leaves for both species. In the untreated control, most surviving seedlings had developed true leaves by day 22. In contrast, it was not until day 45 that the number of individuals with true leaves peaked in the sulfometuron treated pots. No obvious trends in root nodulations were evident at the conclusion of the study.

Metsulfuron

Increases in metsulfuron rate significantly reduced the probability for Scotch broom seedlings survival but not for Portuguese broom survival (Figure 1). The average weight of surviving Scotch broom seedlings declined with increased metsulfuron rate while the weight of Portuguese broom seedlings was unaffected by metsulfuron.

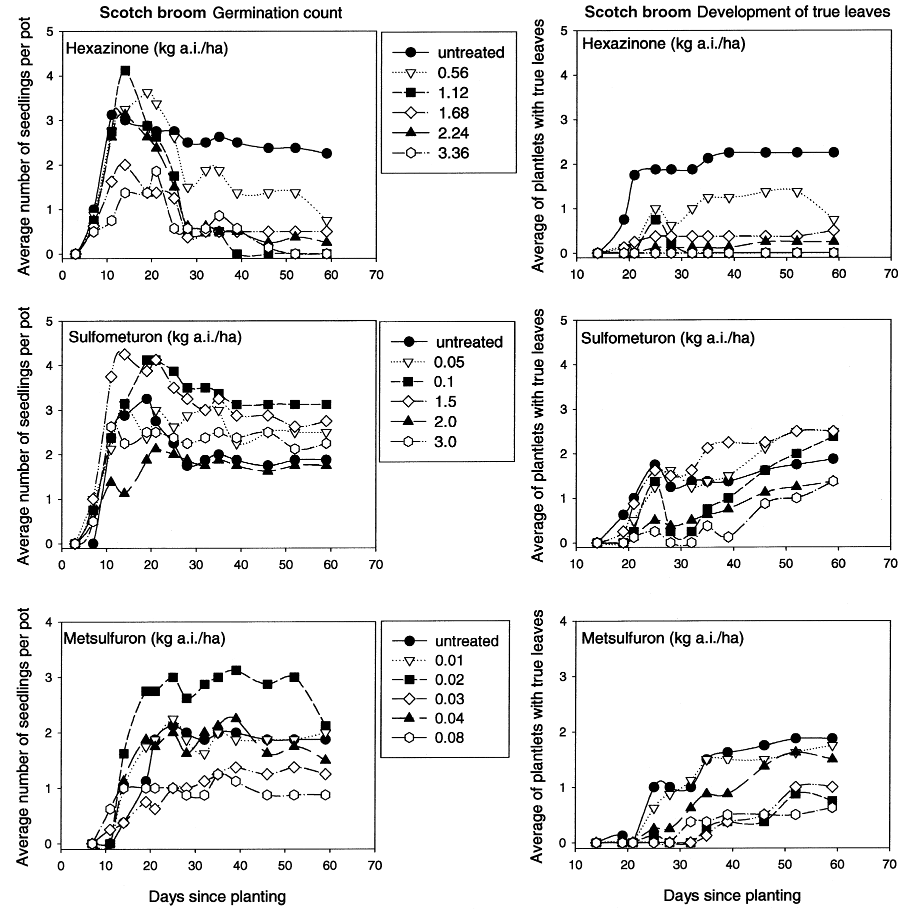

Figure 2. Average germination count of Scotch broom and average number of seedlings with true leaf development per pot (six seed planted per pot) over the nine-week assessment period.

Rate of metsulfuron explained a relatively small amount of variability in Portuguese broom final weight (15%).

For both broom species, seedling germination counts did not increase or decrease greatly after day 22 of the experiment (Figures 2 and 3). Metsulfuron delayed the development of true leaves for both species and this delay was generally greatest at the highest rates. No differences were observed in root nodulations due to metsulfuron applications.

Discussion

Of the three herbicides tested, hexazinone had the greatest impact on broom

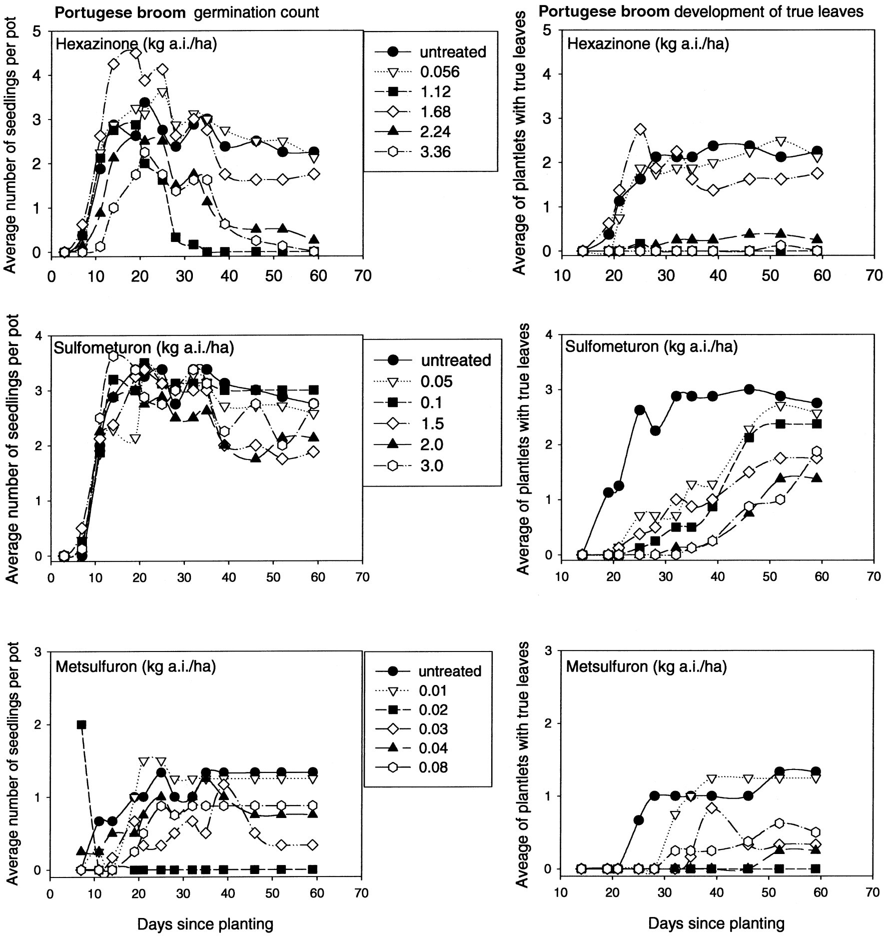

Figure 3. Average germination count of Portuguese broom and average number of seedlings with true leaf development per pot (six seeds planted per pot) over the nine-week assessment period.

seedling growth and establishment. Sulfometuron did not influence the eventual survivorship of either broom species but did result in significant dry weight reductions. Metsulfuron had no discernable effect on Portuguese broom but reduced survivorship and dry weight of Scotch broom.

Once absorbed, hexazinone prevents the production of chemical energy by blocking the flow of electrons through the photosynthetic system (Boger and Sandmann 1989). Additionally, cellular damage results from the build-up of highly reactive photo-products (Ahrens 1994). Thus, membrane damage caused by the excessive build-up of toxic oxygen radicals would explain the increased mortality observed at higher rates of hexazinone. Sulfometuron and metsulfuron both interfere with the enzyme acetolactate synthase, which is required in the synthesis of branched side-chain amino acids (Boger and Sandmann 1989). This slows or stops growth by arresting cell division in the growing points (Ahrens 1994). Thus, plant mortality may not be as rapid with sulfometuron or metsulfuron as with hexazinone.

In field situations survivorship potential of brooms treated with any of the three herbicides would be expected to be lower than those observed in this study. Seedlings are especially susceptible to desiccation because of their limited root systems. Seedlings in this study were kept continually moist. In the field, conditions would be more severe and even short dry periods would likely result in mortality of seedlings with delayed root development. Although root development was not directly measured, true leaf development is often correlated with root development in establishing seedlings (Raven et al. 1981). A delay in true leaf development suggests a similar delay in root development. Timing of leaf development at all rates of hexazinone and sulfometuron suggests that few Scotch broom or Portuguese broom seedlings, and few Scotch broom seedlings treated with metsulfuron would have survived short dry spells in the field.

Hexazinone at 1.68 kg a.i./ha on Portuguese broom and sulfometuron at 0.15 kg a.i./ha on Scotch broom appeared to have little impact on germination and true leaf development. Interestingly, in both cases lower and higher rates had large impacts on growth. We speculate that the pots in these treatments must have realized lower than desired herbicide rates due either to slight skips when sprayed or possibly to greater herbicide leaching as a result of localized variation in the amount of water received from the automatic sprinklers. Another possibility is an error in preparing the spray solution. However we consider this unlikely because the same solution was used to spray both broom species for a given herbicide. The fact that both broom species for a given herbicide at the above rates were not affected similarly suggests the application rate was not responsible.

Other published literature on broom control with the same herbicides used foliar treatments. For example, metsulfuron applied over Scotch broom at a much higher rate than we tested (0.85 kg a.i/ha) was ineffective (Figeuroa 1989). Although these studies indicated that the herbicides were ineffective on mature individuals, our data suggest that these compounds applied preemergence can strongly affect seedling emergence and survival.

The soil used and the procedures maintained in this study make direct herbicide rate comparisons to field situations difficult. We used a sandy loam soil that has a lower cation exchange capacity and less organic matter than many forest soils west of the Cascade Range in the Pacific Northwest. Soils in this region are typically fine in texture and high in organic matter (Franklin and Dyrness 1973). It is difficult to determine if doses received in the field would be greater or less than experienced in the greenhouse. The soil we used would bind the herbicides less than field soils making it more available to plants but the constant watering would increase the potential to leach the herbicide past the rooting zone of establishing seed. By comparison, forest soils higher in OM may bind the herbicide more tightly making it less available to plants and the breakdown of the herbicides by soil organisms may be greater in forests soils than in the sandy loam in this study.

Our results suggest that spring release treatments using hexazinone at even the lowest rate 0.56 kg a.i./ha shows promise in preventing the establishment and spread of broom plants on reforestation sites. At rates approaching normal operational hexazinone applications (1.68–2.24 kg a.i/ha) excellent control of seedlings can be expected. Sulfometuron at operational rates (1.5–2.0 kg a.i./ha) may also provide some preemergence control of both broom species if periods of environmental stress occur. Similarly, metsulfuron may provide some control of Scotch broom at operational rates (.03–.04 kg a.i./ha). Because of poor germination success in the metsulfuron control treatments it is difficult to conclude if Portuguese broom would be strongly affected by this herbicide. Further testing is needed to corroborate our results in the greenhouse to those under field conditions.

Because these herbicides do not effectively control established broom plants, control will depend on proper application timing following disturbance (harvest and mechanical site preparation). Application prior to active seed germination periods will likely increase the effectiveness of these herbicides on both broom species. Broom seed is opportunistic and germinates quickly following physical disturbances such as timber harvest, especially when moisture is available (Mobley 1954; Williams 1981). Hexazinone and sulfometuron are commonly used spring herbicides, but both can damage conifers if sprayed over newly produced conifer foliage (William et al. 1994). Sulfometuron and metsulfuron are often sprayed in the fall prior to planting conifers. Metsulfuron causes damage to conifers if sprayed over foliage in any season and, therefore, must be applied prior to planting (William et al. 1994). Considering these limitations, the best opportunity to control broom may be with spring pre-budburst applications of hexazinone or sulfometuron following fall or winter harvests. Similarly, sulfometuron and metsulfuron have the greatest potential to be effective with early fall applications following mid- to late summer harvests. When broom germination occurs during extended periods between harvesting disturbance and herbicide application, the potential for effective control of either broom species with these herbicides will be reduced.

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