

Oxyfluorfen Strongly Affects *Larix occidentalis* but Minimally Affects *Sagina procumbens* in a Bareroot Nursery

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Abstract. Our objective was to evaluate oxyfluorfen for control of birdseye pearlwort (*Sagina procumbens* L.) in a bareroot nursery crop of western larch (*Larix occidentalis* Nutt.) seedlings. Oxyfluorfen applied at rates up to 0.56 kg a.i./ha in a split-plot experiment with combinations and frequencies of pre- and postemergence sprays gave minimal control of birdseye pearlwort. Although preemergence rates 0.42 kg a.i./ha or greater reduced western larch emergence 10% compared with the control, final seedling inventory was similar for rates 0.42 kg a.i./ha or less. Seedlings receiving 0.42 kg a.i./ha or greater grew 30% more biomass than those that received 0.28 kg a.i./ha or less. When applied postemergence, oxyfluorfen reduced the number of larch seedlings at final inventory 9% and those seedlings had 20% less biomass than the control. Oxyfluorfen applied preemergence increased the amount of bare soil (reduced the weed canopy) throughout the production cycle compared with the control but even the most efficacious treatment combinations still had birdseye pearlwort canopy coverage 63% or greater.

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In bareroot nurseries used to produce conifer seedlings for reforestation, production is hampered by weeds. Fumigation, hand treatments, mechanical treatments, and herbicides can all be used to control weeds; herbicides are particularly cost-effective (South and Gjerstad, 1980a). To maximize germination and early growth of desired seedlings, bareroot beds are often treated with pre- and postemergence herbicides immediately after sowing (South and Gjerstad, 1980b). One such herbicide is oxyfluorfen. This diphenyl-ether herbicide is strongly adsorbed on soil, not readily desorbed, and shows negligible leaching with a half-life of 30 to 40 d (South and Gjerstad, 1980b). Oxyfluorfen inhibits protoporphyrinogen oxidase in the chloroplast and leads to cell membrane disruption. It is commonly used to control broadleaf vegetation in agricultural crops (Daugovish et al., 2008; Doohan and Felix, 2012) and bareroot nurseries in which a wide variety of woody species are grown for reforestation and conservation (e.g., South, 1984). In forest nurseries, oxyfluorfen can

reduce the need for hand-weeding in pine crops by up to 76% (Sloan and Thatcher, 1988). Western larch (*Larix occidentalis* Nutt., hereafter referred to as larch) seedlings have been reported, however, to be more sensitive to herbicides than pines (*Pinus* L.) or true firs (*Abies* Mill.) (Boyd, 1984; Duncan et al., 2008). This is unfortunate because larch is a valued timber species with productivity rivaling other species within its range that includes the Intermountain Region of western North American, specifically the northern portions of the Cascade and Rocky Mountain ranges in the United States and southern Canada (Schmidt and Shearer, 1990).

Birdseye pearlwort (*Sagina procumbens* L., hereafter referred to as pearlwort) is a common, difficult-to-control weed in container nurseries across the United States (Altland, 2013; Judge et al., 2005). Some indicate this perennial, herbaceous weed is native to several Canadian provinces (USDA NRCS, 2013), whereas others show it native to Europe (FNA, 2005). Regardless, it is now widespread across the United States except in areas where soil conditions are less favorable (not cool and moist): Prairie states, the desert Southwest, and the Gulf Coast states (Midwest Weeds, 2013; USDA NRCS, 2013). Pearlwort is a low-growing stoloniferous perennial with linear, awl-like, fleshy leaves on slender stems. It produces prodigious amounts of greenish white flowers (Midwest Weeds, 2013). In at least one bareroot forest nursery in the Pacific Northwest, pearlwort has become a problematic weed. Its robust growth in early spring, particularly when cool and wet weather predominates, allows it to overtop emerging, slower-growing crop seedlings. If the desired crop seedlings are not directly overtopped and killed, pearlwort reduces seedling growth through resource competition. A single plant averages 4600 seeds, although some plants can generate more than 26,000 seeds (Salisbury, 1976) that can be dispersed 40 to 75 cm (Altland, 2006). These tiny seeds (0.3 mm diameter) can form an extensive seedbank in terms of number (greater than 30,000 seeds/m²), depth (10 cm), and longevity (7+ years) (Akinola et al., 1998; Pakeman and Small, 2005).

Because of the limited work done with pearlwort in bareroot nurseries and its deleterious effects on emerging conifer seedlings, nursery managers were interested in whether oxyfluorfen could be safely used in larch crops to control pearlwort. Some work with Japanese larch [*Larix kaempferi* (Lam.) Carrière] suggests it could have merit (Abrahamson and Jares, 1984). Our research objectives were to investigate 1) the effects of oxyfluorfen on larch seedling emergence and growth when applied preemergence and postemergence; and 2) the subsequent efficacy of oxyfluorfen to control pearlwort.

Materials and Methods

This study was conducted at the U.S. Department of Agriculture (USDA), Forest Service nursery in Coeur d'Alene, ID (lat.

47°43'2" N, long. 116°49'34" W, 688 m elevation). The nursery is on an outwash terrace of glaciofluvial deposits. The Marble series soil (mixed, mesic, Lamellic Xeropsammets) is a coarse sandy loam to a depth of 44 cm with an overall depth to gravel of 107 cm (Soil Survey Staff, 2011) having a plow layer pH of 6.9 and an organic matter content of 2.5% (A. Eramian, personal communication). During Sept. 2010, the field was fumigated with dazomet (Basamid® G Granular Soil Fumigant; Certis USA LLC, Columbia, MD) at 390 kg a.i./ha following label directions. On 1 June 2011, larch seeds (seedlot LAOC6960, Kootenai National Forest, lat. 48°53'48" N, long. 115°43'17" W, 1310 m, 92% germination, 96% purity) that had been stratified 28 d were operationally sown with a J.E. Love/Oyjord seeder (J.E. Love Co., Garfield, WA) into eight formed nursery beds at a rate, based on the germination test, to yield 345 seedlings per running meter of nursery bed at final inventory. Seeds were sown in seven rows 15 cm apart. Each bed was 1.2 m wide by at least 113 m long with 46 cm between beds. Immediately after sowing, beds were mulched with EcoFibre® hydromulch (3.7 L·m⁻²; Profile Products, LLC, Buffalo Grove, IL) and irrigated.

Treatments. Our split-split-plot experiment was applied with four replications. The whole plot treatment was oxyfluorfen (Goal® 2XL; Dow AgroSciences, Indianapolis, IN) applied preemergence on 3 June over the larch seeds at four rates: 0, 0.28, 0.42, and 0.56 kg a.i./ha. These rates follow label recommendations for conifer seedbeds (Dow AgroSciences, 2013a, 2013b) and control of dwarf pearlwort (*Sagina apetala* Ard.) (Dow AgroSciences, 2013b), a similar but annual species compared with birdseye pearlwort (USDA NRCS, 2013); birdseye pearlwort is not listed on the label. The split-plot treatment was oxyfluorfen applied one, two, or three times over germinated larch seeds and the split-split-plot treatment was the rate of those applications: 0, 0.28, 0.42, and 0.56 kg a.i./ha. Thus, we installed 192 plots (four preemergence rates by three postemergence applications by four replications) with each plot being 1.2 m wide × 4.6 m long. A 1.5-m-long buffer was included at the ends of each bed.

On 3 June, the whole plot treatments were applied following label instructions and using a nursery-designed 3-point power takeoff power sprayer calibrated to apply 280 L/ha at 170 kPa using TeeJet 8006 VisiFlo Even Flat Spray nozzles (TeeJet Technologies, LLC, Wheaton, IL). The first, second, and third postemergence applications were made with the same power sprayer and operator on 7 July, 28 July, and 13 Oct.

Seedlings were grown operationally following established nursery procedures. From June through July, predawn seedling water potential was kept between 0 and -0.5 MPa through three 45-min irrigation events per week. Beginning in August, seedling moisture stress was increased by reducing irrigation to one or two events per week. Seedlings

were fertilized with ammonium sulfate (21N-0P-0K) at a rate of 47 kg nitrogen (N)/ha on 15 June and ammonium phosphate (16N-8.7P-0K) at a rate of 36 kg N/ha on 15 Sept.

Measurements. To determine seedling emergence, we placed a 30 cm × 90-cm wide (inside dimensions) polyvinyl chloride frame perpendicular to the seedling rows at the center of each plot 28 d after sowing (29 June). To facilitate counting, this frame was subdivided into three 30 cm × 30-cm zones and allowed all seven seedling rows to be included. By this time, epigeal germination appeared complete as emerging cotyledons had shed their seed-coats. At the end of the experiment (24 Oct.) the same frames were used to determine the number of live seedlings (final inventory). On 25 Oct., the seedlings at the midpoint of each plot occupying the center three rows for a distance of 30 cm were carefully excavated to a soil depth of 20 cm. Because the level of pearlwort appeared uniform across treatments, we similarly excavated 10 randomly chosen 30 cm × 30-cm samples near the centers of plots to estimate biomass. Plant samples were sent to the USDA Forest Service Rocky Mountain Research Station in Moscow, ID. For larch, the number of seedlings was recorded per plot, roots were carefully washed, separated from shoots, and tissues (composited within a tissue type for each plot) were dried at 60 °C to constant weight. Seedling biomass was then calculated as the composited biomass divided by the number of seedlings. For pearlwort, roots were carefully washed but not separated from shoots; the entire plant was dried at 60 °C to constant weight and the amount of biomass estimated per hectare.

We measured the percentage of each plot covered by bare soil, larch seedlings, and pearlwort during the experiment. Using the frame described previously and similarly positioned, we took digital photographs of the center zone in the frame for each plot before each postemergent application (6 and 27 July and 5 Oct.). We used the methods of Steinfeld et al. (2011) with a 10 × 10 grid of circles to determine the extent of coverage in each plot.

Data analysis. For our split-split-plot experiment, we used the PROC GLIMMIX function in SAS (SAS Institute, Cary, NC). Independent variables were preemergence rate, number of postemergence applications, and postemergence rate. Differences in the dependent variables (seedling emergence, final inventory, biomass, and percentage cover of bare soil, larch, and pearlwort) were identified. Type III tests of fixed effects were used to examine interactions and main effects. When the F test for a given dependent variable was significant at $P \leq 0.05$, we separated means using Tukey-Kramer adjusted for multiple comparisons.

Results and Discussion

Birdseye pearlwort response. Interactions among the three independent variables (pre- and postemergence application rate and number of postemergence applications of oxyfluorfen) were absent, but preemergence application rate significantly affected canopy cover. Five weeks after the preemergence application, ≈43% of each control plot was covered by pearlwort, whereas all rates of oxyfluorfen yielded significantly ($P < 0.0001$) less weed coverage, and the highest rate

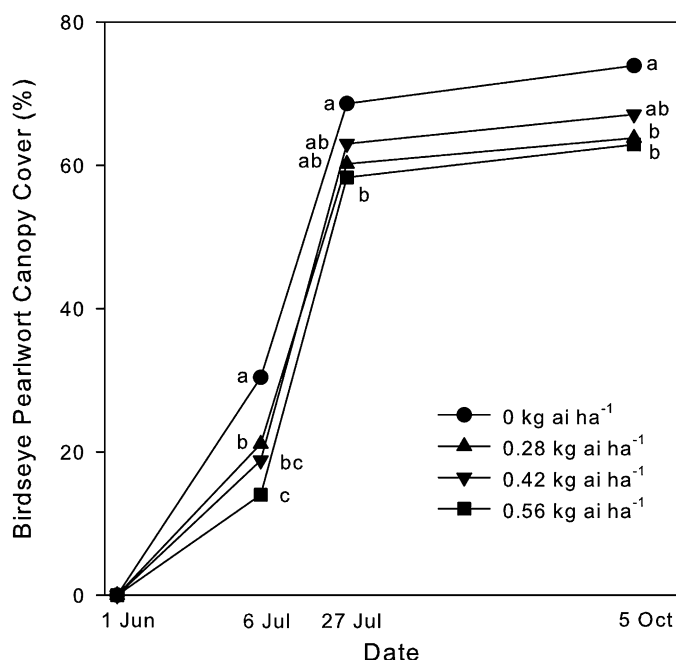


Fig. 1. Percentage of birdseye pearlwort canopy cover during the growing season. Western larch seeds were sown 1 June and canopy cover was assessed 6 July, 27 July, and 5 Oct. immediately before the postemergence applications of oxyfluorfen. Different letters among application rates for each date indicate significantly different values at $\alpha = 0.05$.

(0.56 kg a.i./ha) had half the coverage of pearlwort compared with the control (Fig. 1). This early, relative difference among treatments persisted throughout the production cycle, but the percentage cover of pearlwort at the end of the growing season ranged from 74% in the control to a significantly lower ($P < 0.0001$), but still unacceptable from a nursery manager's perspective, 63% when oxyfluorfen was applied (Figs. 1, 2, and 3). Photoplots show that increases in pearlwort canopy were

mainly caused by growth of plants that occurred despite application of preemergence oxyfluorfen rather than appearance of additional weeds later in the growing season (Fig. 2). In fact, postemergence oxyfluorfen applied one to three times had no effect on canopy cover (data not shown) and the canopy cover of pearlwort doubled between the first and second postemergence applications (Figs. 1 and 2). The Canadian label for Goal® 2XL (Dow AgroSciences, 2013b) indicates that the lowest rate we used (0.28 kg a.i./ha) can "suppress" dwarf pearlwort. Although the preemergence applications may initially and statistically "suppress" pearlwort canopy cover, differences rapidly dissipated and were not readily apparent when the plots were viewed in the field at the end of the growing season. Furthermore, pearlwort accounted for greater than 99% of the non-crop canopy cover and its end-of-season biomass greatly exceeded that of the crop when averaged across all treatments ($4000 \text{ kg} \cdot \text{ha}^{-1}$ vs. $960 \text{ kg} \cdot \text{ha}^{-1}$). In container nurseries, better control of pearlwort was realized when oxyfluorfen was combined with oryzalin or pendimethalin (Altland, 2013; Judge et al., 2005).

Western larch response to preemergence applications. Similar to pearlwort, interactions among the three independent variables were absent. Preemergence application rate of oxyfluorfen significantly affected (all $P \leq 0.0043$) every measured dependent variable (Table 1). The two highest preemergence application rates (0.42 and 0.56 kg a.i./ha) reduced emergence 10% compared with the control (0 kg a.i./ha). The 0.28-kg a.i./ha rate was intermediate, yielding results similar to the control and the two highest rates (Table 1). The fall inventory revealed that the most

seedlings were produced in the control treatment and the least occurred in the highest oxyfluorfen rate (0.56 kg a.i./ha, 10% less than the control) with the 0.28 and 0.42-kg a.i./ha rates being intermediate (similar) to the control and highest rate (Table 1). Seedling root biomass, shoot biomass, and total biomass were, however, significantly greater with increasing preemergence application rate (Table 1). The two highest preemergence application rates (0.42 and 0.56 kg a.i./ha) resulted in an average increase in root, shoot, and total biomass of 32%, 41%, and 36%, respectively, compared with the control. Again, the 0.28-kg a.i./ha rate was intermediate, yielding results similar to the control and the 0.42-kg a.i./ha rate (Table 1).

In general, oxyfluorfen rates ranging from 0.3 to 1.1 kg a.i./ha were compatible with a variety of pine species (Abrahamson and Burns, 1979; Gjerstad and South, 1981). Even a preemergence rate of 1.7 kg a.i./ha failed to harm ponderosa pine (*Pinus ponderosa* Laws. var. *ponderosa*), although it did reduce germination of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) (Abrahamson and Burns, 1979). Our rates of Goal® 2XL applied preemergence to larch reflected the acceptable range (1.12 kg a.i./ha or less) provided on the U.S. label for conifer seedbeds, although no *Larix* species are listed (Dow AgroSciences, 2013a). In contrast, the Canadian version of the label (Dow AgroSciences, 2013b) includes eastern larch [*Larix laricina* (Du Roi) K. Koch.] and application rates of 0.12 to 0.24 kg a.i./ha, the maximum rate being similar to our lowest application rate (chemical formulations for the United States and Canada are the same; V. Peterson, personal communication). We noted no

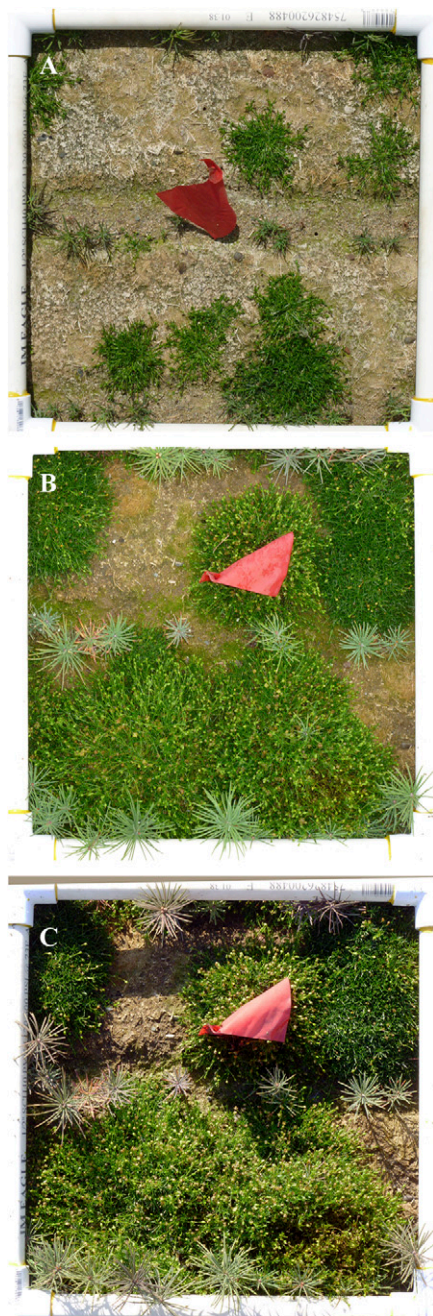


Fig. 2. A series of photos from the center of a single plot treated with 0.28 kg a.i./ha preemergence and no postemergence applications of oxyfluorfen. Photos were taken 6 July (A), 27 July (B), and 5 Oct. (C) immediately before postemergence applications of oxyfluorfen. Note the expansion of existing birdseye pearlwort plants rather than appearance of new plants.

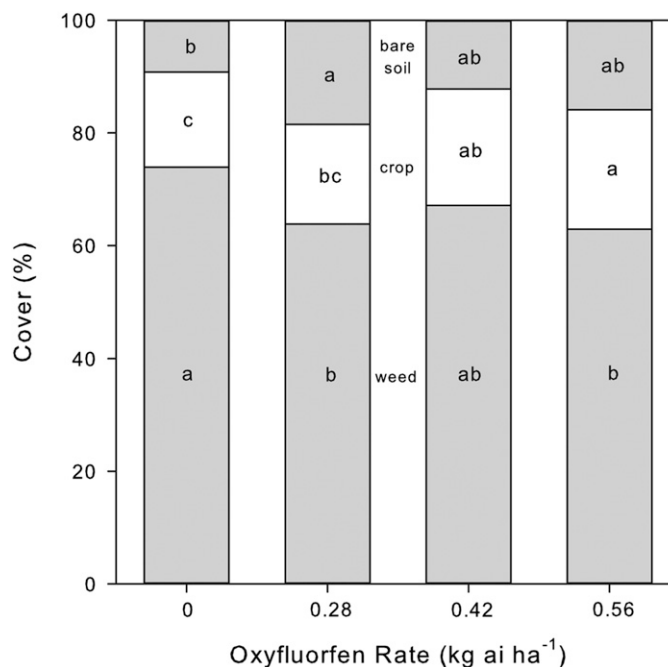


Fig. 3. Percentage of bare soil and western larch and birdseye pearlwort canopy cover at the end of the growing season (5 Oct.) resulting from preemergence applications of oxyfluorfen. Different letters among application rates within a cover category indicate significantly different values at $\alpha = 0.05$.

Table 1. Western larch emergence and growth responses (means and SEs) to oxyfluorfen treatments at the U.S. Department of Agriculture Forest Service nursery in Coeur d'Alene, ID.

Timing	Oxyfluorfen		Seedlings (number/m ²)		Biomass (g/seedling)		
	Rate (kg a.i./ha)	Number of applications	Emerg	Final inventory	Root	Shoot	Total
Preemergence (R)	0	1	541 a	341 a	0.126 c	0.118 c	0.243 c
	0.28	1	511 ab	336 ab	0.138 bc	0.132 bc	0.270 bc
	0.42	1	489 b	330 ab	0.157 ab	0.158 ab	0.315 ab
	0.56	1	496 b	311 b	0.173 a	0.174 a	0.348 a
SE			12	19	0.012	0.012	0.023
Postemergence (A)		1	—	330	0.151	0.143	0.295
		2	—	440	0.149	0.145	0.294
		3	—	322	0.144	0.149	0.293
SE				18	0.011	0.012	0.022
Postemergence (P)	0	1 to 3 ^z	—	348 ^y a	0.173 ^y a	0.166 ^y a	0.338 ^y a
	0.28	1 to 3	—	326 ab	0.144 b	0.136 b	0.280 b
	0.42	1 to 3	—	319 b	0.140 b	0.146 ab	0.286 b
	0.56	1 to 3	—	315 b	0.137 b	0.134 b	0.271 b
SE				19	0.012	0.012	0.023
Source of variation	df				P values		
R	3		0.0043	0.0194	<0.0001	<0.0001	<0.0001
A	2		—	0.5260	0.6673	0.8083	0.9967
R × A	6		—	0.2024	0.1353	0.1040	0.0845
P	3		—	0.0060	0.0003	0.0101	0.0010
R × P	9		—	0.7523	0.1886	0.2509	0.1566
A × P	6		—	0.5570	0.9798	0.9003	0.9851
R × A × P	18		—	0.6062	0.9096	0.2122	0.5019

^zPostemergence (A) was the split-plot (number of applications), and postemergence (P) was the split-split plot (rate of application applied one to three times).

^yMean for each postemergence rate (P) is the average value of all applications.

reduction in any of the dependent variables compared with the control when oxyfluorfen was applied at 0.28 kg a.i./ha. At preemergence rates 0.42 kg a.i./ha or greater, however, emergence and final inventory of larch seedlings was significantly reduced compared with the control, whereas biomass was significantly increased. Although increases in growth are associated with decreases in seed-bed density, it seems unlikely that all of the 36% increase in growth is attributable to herbicide-caused decreases in density. Carneiro et al. (2007) found that a 10% reduction in loblolly pine (*Pinus taeda* L.) bed density yielded a 3% increase in biomass and only observed a 30% increase in biomass when density was greatly reduced (i.e., from 625 to 278 seedlings/m²). Similarly, South et al. (1990) only showed large increases in loblolly pine biomass (28% to 59%) when densities were reduced by ≈50%. These changes in density are much larger than what we observed (i.e., 350 to 320 seedlings/m²). Instead, it may be that oxyfluorfen had a stimulatory effect on larch. It is well known that hormesis can occur in higher plants receiving sublethal doses of herbicides, and Cedergreen et al. (2007) reported herbicide-induced biomass increases as great as 38%, an amount similar to our observations.

Western larch response to postemergence applications. As with preemergence applications, interactions among the three independent variables were absent. Although none of the dependent variables was affected by the number of postemergence applications of oxyfluorfen (all $P \geq 0.5$), they were significantly (all $P \leq 0.01$) affected by postemergence rate (Table 1). Similar to the results for preemergence application rate, the two highest postemergence application rates (0.42 and 0.56 kg

a.i./ha) reduced the final inventory ≈10% compared with the control. The 0.28-kg a.i./ha rate was intermediate, yielding results similar to the control and the two highest rates. Contrary to results for preemergence application rate, increasing postemergence application rate reduced seedling root, shoot, and total biomass compared with the control an average of 23%, 20%, and 21% among rates, respectively (Table 1). Results were similar for percentage canopy cover (data not shown). This is not surprising because oxyfluorfen is considered to be more active as a postemergence than preemergence herbicide (South and Gjerstad, 1980a). Although low rates of (0.3 and 0.6 kg a.i./ha) caused no harm to ponderosa pine (Abrahamson and Burns, 1979) or southern pine species (South and Gjerstad, 1980a), they reduced survival of lodgepole pine (Abrahamson and Burns, 1979) and higher rates (0.8 and 1.7 kg a.i./ha) injured blue spruce (*Picea pungens* Engelm.) (Alspach and Neill, 1980).

In summary, oxyfluorfen (Goal® 2XL) applied preemergence at 0.28 kg a.i./ha over larch seeds in a northern Idaho bareroot nursery yielded similar emergence and biomass values as the control. Preemergence rates 0.42 kg a.i./ha or less yielded similar final inventory numbers as the control, but seedlings exposed to 0.42 kg a.i./ha or greater had 10% less emergence and 36% more total biomass. Postemergence applications, at any rate tested (0.28 to 0.56 kg a.i./ha), reduced larch emergence 10% and seedling biomass 21%. Although preemergence oxyfluorfen at any rate decreased early canopy cover of pearlwort, and this relative improvement persisted throughout the growing cycle, the overall abundance of this weed (63% or greater) indicates that oxyfluorfen offers minimal control of pearlwort.

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