New and Emerging Herbicide Tools for Weed Control in Conifer Nurseries

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Miller T, Peachey E. 2014. New and Emerging Herbicide Tools for Weed Control in Conifer Nurseries. In: Wilkinson KM, Haase DL, Pinto JR, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2013. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-72. 57-61. Available at: http://www.fs.fed.us/rm/pubs/rmrs_p072.html

Abstract: Testing of new herbicides, alone or in combination with currently registered herbicides, is necessary to control weed species without causing damage to tender tree seedlings. In this study, several herbicides were tested for selectivity on seedling conifers during 2011. Trials were conducted at two sites operated by the Weyerhaeuser Company, one at the Aurora Forest Nursery near Aurora, Oregon, and the second at the Mima Forest Nursery, near Olympia, WA. Weed control at Mima exceeded 85% most of the season. At Aurora, all preemergence (PRE) treatments initially provided excellent control, although control with indaziflam had decreased to 71% by August. At Mima, Douglas-fir seedlings were injured by PRE applications of flumioxazin and flumioxazin + pyroxasulfone, and by postemergence (POST) applications of imazamox and fluroxypyr. At Aurora, Douglas-fir seedlings were injured most by fluroxypyr, imazamox and saflufenacil. Western hemlock seedling shoot weight was reduced by indaziflam and fluroxypyr, while imazamox and the split-applications of mesotrione also decreased hemlock shoot height at harvest.

Key Words: Douglas-fir, western hemlock, *Pseudotsuga menziezii*, *Tsuga heterophylla*, pest management

Introduction

Bareroot forest tree nurseries grow trees from seed, rooted cuttings, or from smaller trees transplanted into the nursery. Field nurseries produce tree seedlings that are used to regenerate lands that have been harvested, or destroyed by disease or fire. These nurseries also grow seedlings for the Christmas tree industry, or for ornamental and pharmaceutical markets.

Pest management is a significant nursery challenge. Weeds represent the second most problematic pest in bareroot Pacific Northwest nurseries, with the biggest problem being disease from soil-borne, stem, and foliar pathogens (Masters 2009). A typical tree marketed from bareroot nurseries in the Pacific Northwest is a two-year-old tree (Weiland and others 2011). Reduced growth due to weed competition results in a tree seedling of lower vigor and quality, and may result in an inability to meet customer expectations and a loss of business in future years. In addition, tree seedlings contaminated with certain weed species (such as yellow nutsedge, *Cyperus esculentus*) may result in a quarantine that prevents certain lots from being sold at all (WSDA 2013). To put this into perspective, in 2003, Washington State planted nearly 111,000 acres, and its nurseries shipped 118 million trees at an estimated value of $11.2 million. Production is similar for Oregon (Weiland and others 2011). Trees of poor vigor or those contaminated with weed propagules can sometimes be replaced, but usually won't be replaced with those of the same genetic potential. The value of genetically improved trees is reflected in an average net present value contribution of $50 per acre over trees planted with unimproved seedlings, which could yield as much as $5.0 million net present value (NPV) annually based on current production (Masters 2009).

While fumigation is helpful, it generally provides only partial weed control and is usually augmented with herbicides followed by periodic hand weeding. Registered herbicides either do not provide adequate control of many weed species, or do not persist long enough to control later-germinating weeds. Testing of new herbicides, alone or in combination with currently registered herbicides, is necessary to fully control these species without causing damage to tender tree seedlings.

Materials and Methods

Trials were conducted at two sites operated by the Weyerhaeuser Company, one at the Mima Forest Nursery, near Olympia, Washington and the second at the Aurora Forest Nursery near Aurora, Oregon. Douglas-fir (*Pseudotsuga menziezii*) seedlings were included at both sites, while western hemlock (*Tsuga heterophylla*) seedlings were included at Aurora. Seedlings were transplanted in late May and soil was allowed to firm from rainfall as tree seedlings hardened for at least three days. Plots (8 by 8 ft [2.4 by 2.4 m]) were established prior to budbreak and preemergence (PRE) herbicides were applied May 23 at Aurora and June 1 at Mima. CO_2-pressurized backpack sprayers were used for both applications. Following budbreak, postemergence (POST) herbicides were applied June 28 at Mima and July 29 at Aurora. Application information is included in table 1. Weed control and crop injury were visually estimated June 28 and August 9 at Mima, and height of three randomly selected trees in each treatment was measured August 9. At Aurora, weed control and crop injury were evaluated June 16 and July 29, and weed control August 11. The height of ten consecutive trees from the center of each plot was measured July 29. Ten adjacent trees from randomly selected locations in each plot were harvested on October 17 at Aurora and December 6 at Mima, and shoot and root weight, shoot length, stem caliper, and general observations on seedling defects (chlorosis, stem straightness, and so on) were recorded. Data were analyzed using SAS, and means were separated using Fisher's Protected Least Significant Difference (LSD) (P = 0.05).

Results

Weed Control

At Mima, weed control exceeded 90% for all treatments (table 2). Non-treated plots and plots just prior to hand weeding, estimated at 84 to 88% control (16 and 12% weed cover). Primary weeds at Mima were annual bluegrass (*Poa annua*), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), common groundsel (*Senecio vulgaris*), and dandelion (*Taraxacum officinale*).

At Aurora, all PRE treatments were providing excellent control, although control with indaziflam had decreased to 71% by August. POST treatments were uniformly poor, perhaps due to the lateness of the application in relation to date of evaluation. Primary weeds at Aurora were common groundsel (*Senecio vulgaris*), horseweed (*Conyza canadensis*), witchgrass (*Panicum capillare*), and smooth crabgrass (*Digitaria ischaemum*).

Tree Seedlings

At Mima, Douglas-fir seedlings were injured by PRE applications of flumioxazin and flumioxazin + pyroxasulfone, and by POST applications of imazamox and fluroxypyr (table 2). Damage from the PRE applications were needle necrosis and loss, as well as tip die-back and stunting. Damage from the imazamox application was chlorosis of new needle growth. Damage from the fluroxypyr application was needle

Table 1. Herbicide Application information Mima and Aurora forest nurseries (2011).

Timing	Date	Temperature	Wind	Sun	New growth	Moisture
Aurora						
PRE	May 23	55 °F (12.8 °C)	W 0-2 mph (0-3.2 kph)	Clear	Dormant	Damp
POST	July 29	66°F (18.9 °C)	W 0-1 mph (0-1.6 kph)	50% cloud cover	2-6 in (5-15 cm)	Damp
Mima						
PRE	June 1	53 °F (11.7 °C)	Light and variable	Overcast	Dormant	Soil damp, trees dry
POST	June 28	60 °F (15.6 °C)	SW 7-10 mph (11.3-16.1 kph)	Overcast	1-2 in (2.5-5 cm)	Soil dry, trees dry

Table 2. Mid-season weed control and foliar injury to Douglas-fir seedlings at Mima Forest Nursery after treatment with various early-season herbicides (2011).

Treatment[z]	Rate (*product/a*)	Rate (*lb ai/a*)	Timing	Weed control[y] (%)	Foliar injury[y] (%)	Height[x] (*cm*)
Indaziflam	5 fl.oz	0.065	PRE	100 a	0 d	30.5 a
Mesotrione	6 fl.oz	0.188	PRE	100 a	0 d	30.3 a
Dithiopyr	12 fl.oz	0.188	PRE	95 bc	0 d	29.6 ab
Flazasulfuron	2 oz	0.031	PRE	100 a	0 d	27.2 bc
Pendimethalin + dimethenamid-p	200 lb (granule)	3.5 (total)	PRE	99 ab	1 d	30.2 a
Isoxaben	11 oz	0.516	PRE	98 abc	0 d	32.2 a
Oxyfluorfen	1 pt	0.5	PRE	99 ab	0 d	31.0 a
Dithiopyr	7.6 oz	0.19	PRE	96 abc	0 d	32.5 a
Trifluralin + isoxaben	100 lb (granule)	2.5 (total)	PRE	99 ab	0 d	30.1 ab
Flumioxazin	8 oz	0.25	PRE	100 a	28 b	23.7 d
Flumioxazin + pyroxasulfone	8 oz	0.38 (total)	PRE	100 a	29 b	23.8 d
Imazamox	5 fl.oz	0.039	POST	99 ab	6 c	30.5 a
Fluroxypyr	10.7 fl.oz	0.125	POST	94 c	48 a	24.8 cd
Nontreated	---	---	---	88 d	0 d	31.1 a
Hand-weeded	---	---	---	84 d	0 d	30.8 a

Means within a column followed by the same letter or not followed by a letter are not significantly different (LSD0.05).
[z] Treatments were applied June 1 preemergence (PRE) and June 28 postemergence (POST).
[y] Weed control and foliar injury was estimated August 9.
[x] Height of three trees was measured August 9.

necrosis and twisting of the stem and new growth. Height of Douglas-fir trees treated with flumioxazin and flumioxazin + pyroxasulfone, and fluroxypyr was significantly reduced, while trees treated with imazamox generally were symptom-free and of similar height as non-treated trees. At harvest, trees treated with flumioxazin, fluroxypyr, and to a lesser extent, flumioxazin + pyroxasulfone, displayed reduced shoot fresh weight and caliper (table 3). Fluroxypyr treatment reduced stem length by harvest, while trees treated with flumioxazin were shorter than those treated with other herbicides, but similar to the height on non-treated trees.

At Aurora, mid-season evaluations indicated that Douglas-fir seedlings were most sensitive to saflufenacil while western hemlock appeared to be tolerant (table 4). Flumioxazin also reduced the growth of hemlock but not Douglas-fir seedlings. Mesotrione applied twice at 12 oz/acre caused significant foliar injury and reduced hemlock seedling height, while Douglas-fir seedlings were unaffected. At harvest, Douglas-fir seedlings were impacted most by fluroxypyr, imazamox and saflufenacil (table 5). Western hemlock seedling shoot weight was reduced by indaziflam and fluroxypyr, while imazamox and the split-applications of mesotrione also decreased hemlock shoot height at harvest (table 6). Western hemlock was unaffected by saflufenacil. Neither root weight nor stem caliper of western hemlock were significantly affected by herbicide application.

Table 3. Effect of early-season herbicides at harvest of Douglas-fir at Mima Forest Nursery (2011).

Treatment[z]	Rate (*product/a*)	Rate (*lb ai/a*)	Timing	Shoot[y] (*g*)	Root (*g*)	Height (*cm*)	Caliper (*mm*)
Indaziflam	5 fl.oz	0.065	PRE	316 a	75	42.5 ab	7.3 a
Mesotrione	6 fl.oz	0.188	PRE	303 ab	69	39.7 abc	7.0 abc
Dithiopyr	12 fl.oz	0.188	PRE	288 ab	68	40.5 abc	6.7 abc
Flazasulfuron	2 oz	0.031	PRE	322 a	85	42.7 ab	7.1 abc
Pendimethalin + dimethenamid-p	200 lb (granule)	3.5 (total)	PRE	270 abc	60	40.2 abc	6.9 abc
Isoxaben	11 oz	0.516	PRE	297 ab	63	42.7 ab	7.0 abc
Oxyfluorfen	1 pt	0.5	PRE	297 ab	74	43.3 a	7.2 ab
Dithiopyr	7.6 oz	0.19	PRE	289 ab	67	43.7 a	7.1 abc
Trifluralin + isoxaben	100 lb (granule)	2.5 (total)	PRE	302 ab	72	41.9 ab	7.0 abc
Flumioxazin	8 oz	0.25	PRE	205 cd	63	33.0 d	6.3 c
Flumioxazin + pyroxasulfone	8 oz	0.38 (total)	PRE	227 bc	68	35.2 cd	6.6 abc
Imazamox	5 fl.oz	0.039	POST	286 ab	66	37.5 bcd	6.6 abc
Fluroxypyr	10.7 fl.oz	0.125	POST	132 d	34	33.2 d	5.5 d
Nontreated	—	—	—	295 ab	70	41.8 ab	6.5 bc
Hand-weeded	—	—	—	267 abc	67	41.0 ab	6.4 bc

Means within a column followed by the same letter or not followed by a letter are not significantly different (LSD0.05).
zTreatments were applied June 1 preemergence (PRE) and June 28 postemergence (POST).
yShoot and root weight, shoot height, and stem caliper were measured December 6.

Table 4. Mid-season weed control and foliar injury to Douglas-fir and western hemlock seedlings at Aurora Forest Nursery after early-season treatment with various herbicides (2011).

Treatment[z]	Rate (*product/a*)	Rate (*lb ai/a*)	Timing	Weed control[y] (*%*)	Douglas-fir Foliar injury[y] (*%*)	Douglas-fir Height[x] (*cm*)	Western hemlock Foliar injury[y] (*%*)	Western hemlock Height[x] (*cm*)
Indaziflam	5 fl.oz	0.065	PRE	71 bc	0.5 fg	26.6 a	1.5 de	17.6 a-d
Mesotrione	6 fl.oz	0.188	PRE	98 ab	2.8 bcd	26.3 a	4.5 a	16.3 bcd
Dithiopyr	12 fl.oz	0.188	PRE	83 abc	1.3 d-g	28.3 a	1.5 de	18.0 a-d
Flazasulfuron	2 oz	0.031	PRE	91 abc	2.8 bcd	25.1 ab	2.0 cd	21.0 a
Pendimethalin + dimethenamid-p	200 lb (granule)	200 (total)	PRE	87 abc	2.3 b-f	26.2 a	1.5 de	20.2 ab
Isoxaben	11 oz	0.516	PRE	97 ab	2.3 b-f	28.2 a	1.3 def	18.1 a-d
Oxyfluorfen	1 pt	0.5	PRE	93 abc	0.8 efg	28.3 a	2.1 cd	19.1 abc
Trifluralin + isoxaben	100 lb (granule)	100 (total)	PRE	89 abc	1.5 c-g	25.3 ab	1.5 de	20.2 ab
Flumioxazin	8 oz	0.25	PRE	88 abc	3.3 bc	24.9 ab	4.0 ab	14.7 d
Flumioxazin + pyroxasulfone	8 oz	0.38 (total)	PRE	96 ab	2.5 b-e	24.8 ab	3.0 bc	17.1 a-d
Imazamox	5 fl.oz	0.039	POST	0 d	2.5 b-e	27.2 a	2.0 cd	17.9 a-d
Fluroxypyr	10.7 fl.oz	0.125	POST	18 d	0.5 fg	24.1 ab	0.5 ef	20.1 ab
Nontreated	---	---	---	20 d	0.0 g	21.3 b	0.5 ef	20.2 ab
Hand-weeded	---	---	---	98 ab	0.0 g	25.5 ab	0.0 f	17.9 a-d
Mesotrione + mesotrione	6 fl.oz + 6 fl.oz	0.188 + 0.188	PRE + POST	99 ab	2.8 bcd	25.9 ab	4.5 a	20.3 ab
Mesotrione + mesotrione	8 fl.oz + 8 fl.oz	0.25 + 0.25	PRE + POST	98 ab	2.5 b-e	26.8 a	5.3 a	21.1 a
Mesotrione + mesotrione	12 fl.oz + 12 fl.oz	0.375 + 0.375	PRE + POST	100 a	3.8b	28.3 a	4.8 a	15.1 cd
Saflufenacil	1 oz	0.044	PRE	68 c	7.7 a	21.8 b	1.5 de	17.4 a-d

Means within a column followed by the same letter or not followed by a letter are not significantly different (LSD0.05).
[z] Treatments were applied May 23 preemergence (PRE) and July 29 postemergence (POST).
[y] Foliar injury was rated June 26, weed control was rated July 29.
[x] Height of ten trees was measured July 29.

Table 5. Effect of early-season herbicides at harvest of Douglas-fir at Aurora Forest Nursery (2011).

Treatment[z]	Rate (*product/a*)	Rate (*lb ai/a*)	Timing	Shoot[y] (*g*)	Root[y] (*g*)	Height[y] (*cm*)	Caliper[y] (*mm*)
Indaziflam	5 fl.oz	0.065	PRE	214 a	110 ab	33.0 ab	6.4 a
Mesotrione	6 fl.oz	0.188	POST	175 abc	93 abc	31.0 ab	5.9 abc
Dithiopyr	12 fl.oz	0.188	PRE	184 abc	93 abc	34.0 ab	5.8 a-e
Flazasulfuron	2 oz	0.031	PRE	188 abc	119 ab	31.5 ab	6.0 ab
Pendimethalin + dimethenamid-p	200 lb (granule)	200 (total)	PRE	166 abc	101 ab	32.5 ab	5.4 b-e
Isoxaben	11 oz	0.516	PRE	201 a	124 ab	35.8 a	5.5 a-e
Oxyfluorfen	1 pt	0.5	PRE	198 ab	106 ab	35.8 a	6.0 ab
Trifluralin + isoxaben	100 lb (granule)	100 (total)	PRE	143 bc	135 a	30.0 b	5.0 de
Flumioxazin	8 oz	0.25	PRE	198 ab	106 ab	34.1 ab	6.0 ab
Flumioxazin + pyroxasulfone	8 oz	0.38 (total)	PRE	201 a	109 ab	33.8 ab	6.0 ab
Imazamox	5 fl.oz	0.039	POST	141 bc	83 bc	30.9 ab	4.9 e
Fluroxypyr	10.7 fl.oz	0.125	POST	135 c	78 bc	29.6 bc	5.0 cde
Nontreated	---	---	---	164 abc	103 abc	31.9 ab	5.7 a-e
Hand-weeded	---	---	---	160 abc	108 ab	33.1 ab	5.8 a-e
Mesotrione + mesotrione	6 fl.oz + 6 fl.oz	0.188 + 0.188	PRE + POST	174 abc	141 a	30.0 b	5.8 a-d
Mesotrione + mesotrione	8 fl.oz + 8 fl.oz	0.25 + 0.25	PRE + POST	189 abc	115 ab	32.4 ab	5.9 a-d
Mesotrione + mesotrione	12 fl.oz + 12 fl.oz	0.375 + 0.375	PRE + POST	215 a	116 ab	34.0 ab	6.1 ab
Saflufenacil	1 oz	0.044	PRE	65 d	55 c	24.9 c	4.1 f

Means within a column followed by the same letter or not followed by a letter are not significantly different (LSD0.05).
[z] Treatments were applied May 23 preemergence (PRE) and July 29 postemergence (POST).
[y] Shoot and root weight, shoot height, and stem caliper were measured October 17.

Table 6. Effect of early-season herbicides at harvest of western hemlock at Aurora Forest Nursery (2011).

Treatment[z]	Rate (*product/a*)	Rate (*lb ai/a*)	Timing	Shoot[y] (*g*)	Root[y] (*g*)	Height[y] (*cm*)	Caliper[y] (*mm*)
Indaziflam	5 fl.oz	0.065	PRE	51 e	53	34.0 fg	4.2
Mesotrione	6 fl.oz	0.188	POST	118 bcd	88	38.3 b-f	4.3
Dithiopyr	12 fl.oz	0.188	PRE	126 abc	239	38.8 b-f	4.5
Flazasulfuron	2 oz	0.031	PRE	170 a	193	38.5 b-f	4.6
Pendimethalin + dimethenamid-p	200 lb (granule)	200 (total)	PRE	119 bcd	88	37.9 b-f	5.1
Isoxaben	11 oz	0.516	PRE	161 ab	99	38.0 b-f	5.0
Oxyfluorfen	1 pt	0.5	PRE	138 abc	104	41.0 abc	4.8
Trifluralin + isoxaben	100 lb (granule)	100 (total)	PRE	125 abc	100	40.6 a-d	4.5
Flumioxazin	8 oz	0.25	PRE	123 bc	83	39.1 b-d	4.9
Flumioxazin + pyroxasulfone	8 oz	0.38 (total)	PRE	139 abc	79	42.9 ab	5.0
Imazamox	5 fl.oz	0.039	POST	106 cd	90	34.4 efg	4.6
Fluroxypyr	10.7 fl.oz	0.125	POST	74 de	70	32.6 g	3.9
Nontreated	---	---	---	119 bcd	90	37.0 c-g	4.5
Hand-weeded	---	---	---	73 de	75	35.9 d-g	3.7
Mesotrione + mesotrione	6 fl.oz + 6 fl.oz	0.188 + 0.188	PRE + POST	124 abc	95	35.8 d-g	4.4
Mesotrione + mesotrione	8 fl.oz + 8 fl.oz	0.25 + 0.25	PRE + POST	120 bcd	90	34.5 efg	4.4
Mesotrione + mesotrione	12 fl.oz + 12 fl.oz	0.375 + 0.375	PRE + POST	99 cd	73	32.7 g	4.2
Saflufenacil	1 oz	0.044	PRE	160 ab	145	44.7 a	4.8

Means within a column followed by the same letter or not followed by a letter are not significantly different (LSD0.05).
[z] Treatments were applied May 23 preemergence (PRE) and July 29 postemergence (POST).
[y] Shoot and root weight, shoot height, and stem caliper were measured October 17.

Summary

Even though injury was primarily at Mima only, it appears flumioxazin, flumioxazin + pyroxasulfone, imazamox, and fluroxypyr are potentially too damaging for use on Douglas-fir seedlings. At Aurora, trifluralin + isoxaben and saflufenacil were also marginally to excessively damaging to Douglas-fir seedlings, respectively, while mesotrione caused slight injury. Western hemlock was at least marginally injured by indaziflam, fluroxypyr, imazamox, and the split-applications of mesotrione, although hand-weeded and non-treated western hemlock also displayed slightly reduced growth. A second season of data on non-damaging herbicides from 2011 was collected and will be published as soon as possible. These data will help to determine the potential for registration of those products in conifer seedling nurseries.

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