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Early Survival and Growth of Loblolly Pine Seedlings Treated With Sulfometuron or Hexazinone Plus Sulfometuron in Southwest Arkansas

J. L. Yeiser and E. J. Rhodenbaugh

Professor and research specialist, School of Forest Resources and Arkansas Agricultural Experiment Station University of Arkansas, Monticello, Arkansas

Improved survival and growth of pine (Pinus *spp.*) *seedlings have been observed as a result of herbaceous weed control with sulfometuron, hexazinone, or combinations of the two herbicides. In this study, survival and growth of planted loblolly pine* (Pinus taeda *L.*) *seedlings were assessed two growing seasons after treatment with seven selected rates of hexazinone (1.12, 0.84, 0.75, 0.56, 0.37, 0.28, and 0 kg ai/ha) mixed with 0.10 kg ai/ha sulfometuron and compared to values for untreated (control) seedlings. Treatment with hexazinone– sulfometuron mixtures resulted in greater height and diameter growth than treatment with sulfometuron alone. All seven herbicide treatments resulted in improved survival and increased growth compared to values for untreated seedlings two growing seasons after treatment. Height and diameter growth were greatest with 0.84 kg ai/ha hexazinone mixed with 0.10 kg ai/ha sulfometuron. However, increasing the rate of hexazinone above 0.56 kg ai/ha did not substantially increase growth, indicating that 0.56 kg ailha hexazinone plus 0.10 kg/ha sulfometuron may be the best choice operationally.* Tree Planters' Notes 45(4):116-120; 1994.

Herbaceous weed control has enhanced survival and growth of newly planted loblolly pine seedlings *(Pinus taeda* L.) throughout the South (Nelson and others 1981, Knowe and others 1985, Zutter and others 1986, Creighton and others 1987, Miller and others 1991). Sulfometuron (Oust®) and hexazinone (Velpar® L) have proven to be effective, either alone or in combination, for controlling herbaceous competition about recently planted pine seedlings, resulting in increased survival and growth (Michael 1985, Cantrell and others 1985, Yeiser and Boyd 1989). (Hexazinone is 3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione and sulfometuron is {methyl 2-[[[[(4,6dimethyl-2 pyridmidinyl) amino] carbonyl] amino] sulfonyl] benzoate} .) Early growth increases have been projected into substantial economic gain at the end of a rotation, making investment in herbaceous weed control with either sulfometuron or hexazinone an attractive silvicultural alternative (Atkins 1984, Anderson and others 1986, Busby 1992).

Sulfometuron controls a variety of forbs and grasses but does not control brush or hardwoods. Hexazinone at selected rates has the added advantage of controlling brush and hardwood as well as a variety of herbaceous species (Atkins 1984, Gonzalez 1985, Michael 1985, Anderson and others 1986). In previous studies, sulfometuron-hexazinone mixtures reduced herbaceous competition and stimulated loblolly seedling height and diameter growth above that observed in untreated plots when herbaceous cover was heavy (Yeiser and Boyd 1989) and in a newly planted old field in northern Arkansas (Gardiner and Yeiser 1993). Metcalfe (1985a) reported improved early growth and survival resulting from herbaceous control with sulfometuron and hexazinone mixtures at sites in Kentucky and Virginia. The early growth increment observed in loblolly pine seedlings in these studies points to the need for further examination of sulfometuron-hexazinone combinations for weed control in newly planted pine plantations. Consequently, the objectives of this study were to assess survival and growth responses of loblolly pine seedlings to selected rates of hexazinone mixed with a constant rate of sulfometuron and the costs of treatment.

Methods

The study site is in Miller County near Fouke, Arkansas. The study was established on a poorly drained, mixed pine-hardwood flatwood site that had been recently harvested and the slash wind-rowed and burned prior to bedding. Soils at the site were Wrightsville silt loams, which are deep, poorly drained soils capable of supporting mixed pine-hardwood forests (Laurent 1984). The site index for loblolly pine was 24 m at age 50. Four blocks were established at the site with eight plots in each block. A total of 20 seedlings in two 10-seedling rows were hand-planted on the crest of beds in each plot with 3.05 m between rows and 2.4 m between seedlings in a row. Two rows were planted around the perimeter of the study to serve as a border. Seedlings were hand-planted in February 1987.

Treatments consisted of (1) seven selected rates of hexazinone— 1.12, 0.84, 0.75, 0.56, 0.37, 0.28, and 0 kg of active ingredient (ai)/ha— mixed with 0.10 kg ai/ha sulfometuron and (2) an untreated control. Herbicides were applied in 0.91-m bands, centered over the top of seedling rows, in early April 1987. Herbicides were applied at a rate of 140 L/ha with a two-nozzle handheld CO_2 -pressurized backpack sprayer.

Seedling heights (centimeters) and groundline diameters (gld in millimeters) were measured immediately after planting and at the end of one and two growing seasons. Percentage survival was calculated following the first and second growing seasons by dividing the number of surviving seedlings by the number of seedlings originally planted in each plot. Height and gld growth for each surviving seedling were calculated by subtracting measured height and gld of the previous year from measured height and gld of the current year. For example, first-year height growth was the height measured after one growing season minus initial height; second-year height growth was the height measured after two growing seasons minus first-year height; and total height growth was the second-year height minus the initial height. The same calculations were carried out for gld values.

Herbicide costs were obtained from 1993 prices supplied by a representative of the manufacturer. Prices were given in dollars per ounce (sulfometuron) or gallon (hexazinone) and converted to dollars per hectare. Height and diameter growth per herbicide dollar (centimeter or millimeter per $, cm or mm / $*haG1 were calculated by dividing the total height or gld growth by the dollars per hectare spent on the individual herbicide treatments.

Regression analyses for height and diameter growth were conducted for the continuous variable hexazinone rate. Percentage survival data were transformed with arcsin % %. Real numbers for percentage survival are presented in this paper. Survival and costs were analyzed with analyses of variance according to a randomized complete block design. Means were separated with Duncan's multiple range test. Effects were considered significant at the 0.05 probability level.

Results and Discussion

Survival. Hexazinone rate significantly affected first- and second-year survival (table 1). Percentages and significance levels for second-year survival were nearly identical to first-year survival (with the only exception a 2.5% decrease for 1.12 kg ai/ha hexazinone +0.10 kg ai/ha sulfometuron); therefore only secondyear survival will be discussed. Survival was 80% or greater for treated plots and averaged 75% for the untreated check. The addition of hexazinone, regardless of rate, did not significantly improve survival over that observed for sulfometuron alone. However, all four middle hexazinone rates plus 0.10 kg ai/ha sulfometuron and 0.10 kg ai/ha sulfometuron with no hexazinone significantly improved survival over untreated seedlings. Survival decreased more than 11% when 1.12 kg ai/ha hexazinone was added to the 0.10 kg ai/ha sulfometuron. Other studies have also reported increased pine seedling mortality resulting from application of 1.12 kg ai/ha hexazinone (Metcalfe 1985b), indicating that this level may be harmful to young loblolly pine.

Hexazinone rate-growth relationship. Significant quadratic relationships were delineated for all growth parameters except first-year diameter growth (table 2). Total height or gld growth, which is height or gld following two growing seasons minus initial height or gld, reflects the trends noted in first- and second-year growth. For this reason, the following discussion will be limited to total height and diameter growth. First-

Table 1-*Survival of hand-planted loblolly seedlings 2 years after treatment with hexazinone and sulfometuron (kg ai/ha) for herbaceous weed control in southwest Arkansas*

Pesticide treatment (kg ai/ha)		%
Hexazinone	Sulfometuron	survival
1.12	0.10	80.0 cd
0.84	0.10	96.3 a
0.75	0.10	93.8 ab
0.56	0.10	91.3 abc
0.37	0.10	91.3 abc
0.28	0.10	86.3 bcd
0.0	0.10	91.3 abc
0.0	0.0	75.0 d

Note: Means within a column sharing a letter are not significantly different (Duncan's multiple range test, P # 0.05).

and second-year growth will be included in figures 1 and 2 but will not be discussed.

Total height growth increased significantly two growing seasons after treatment on plots treated with hexazinone (figure 1). Total height growth averaged about 53 cm for untreated seedlings (data not shown) and about 65 cm for sulfometuron alone (the 0 hexazinone rate in figure 1).

Height growth following two growing seasons peaked at 0.84 kg ai / ha hexazinone (figure 1); however, height growth from 0.56 to 0.84 kg ai / ha hexazinone was similar, varying by 0.7 cm (figure 1). Height growth declined sharply between 0.84 and 1.12 kg ai / ha hexazinone, indicating that hexazinone application rates greater that 0.84 kg ai/ha may be harmful to seedlings.

Table 2-*Regression of first-year, second-year, and total height and groundline diameter (gld) growth for the continuous variable hexazinone rate*

Growth variable	b_0	b_1	b_2	R^2	Pr>ITI
Height (cm)					
First-year	18.46	26.85	-18.69	0.88	0.01
Second-year	43.32	72.88	-60.67	0.86	0.01
Total	61.77	99.73	-79.35	0.89	0.01
Diameter (mm)					
First-year	5.18	2.10	-1.56	0.31	0.32
Second-year	9.59	11.13	-7.37	0.86	0.01
Total	14.77	13.23	-8.93	0.84	0.03

Note: Sulfometuron at 0.10 kg/ha was included in all applications of hexazinone. Data included in the table are intercept (b_0), slope of the linear portion (b_1), slope of the quadratic portion (b_2), coefficient of determination (R^2), and the significance level (Pr>ITI). First-year = height or gld following first growing season minus initial height or gld; second-year = height or gld following second growing season minus height or gld following first growing season; total = height or gld following second growing season minus initial height or gld.

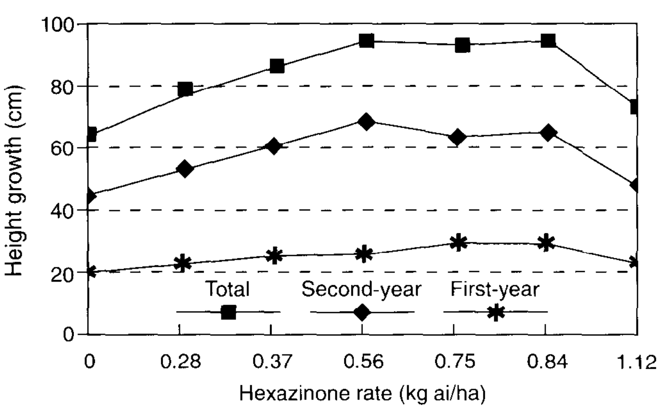

Figure 1—*Height growth from initial through the first growing season (**first-year**), from the first through the second growing season (**second year**), and from initial through the second growing season (**total**) for the continuous variable hexazinone rate. Sulfometuron at 0.10 kg ai/ha was included in all applications of hexazinone.*

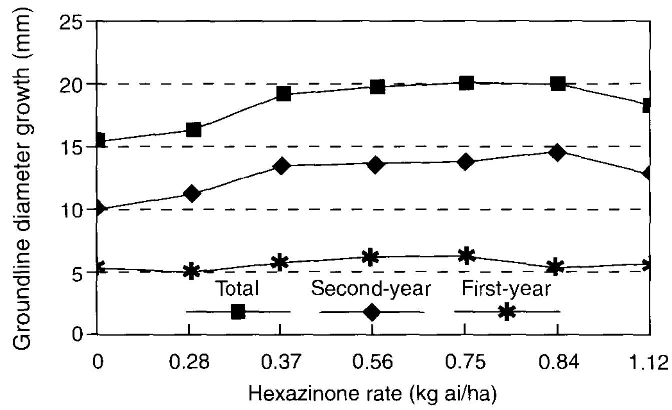

Figure 2—*Groundline diameter growth from initial through the first growing season (**first-year**), from the first through the second growing season (**second year**), and from initial through the second growing season (**total**) for the continuous variable hexazinone rate. Sulfometuron at 0.10 kg ai/ha was included in all applications of hexazinone.*

Diameter growth for untreated seedlings averaged 12.6 mm from planting through the second growing season after treatment (data not shown). Sulfometuron with no hexazinone increased gld growth after two growing seasons by about 3.3 mm (the 0 hexazinone rate in figure 2) but was not significant when compared to untreated seedlings.

Diameter growth two growing seasons after treatment also peaked at the 0.84 kg ai/ha hexazinone rate (figure 2). Diameter growth was, however, nearly level from 0.37 to 0.84 kg ai/ha hexazinone, varying by 0.8 mm (figure 1). As with height growth, diameter growth declined from 0.84 to 1.12 kg ai/ha, although the decline was not as steep as observed for height growth.

These results indicate that the optimal rate of hexazinone mixed with 0.10 kg ai / ha sulfometuron would be 0.84 kg ai/ha. However, given that height and diameter growth did not substantially increase from 0.56 to 0.84 kg ai / ha, hexazinone added at the 0.56 kg ai/ha rate may be the more appropriate treatment for operational use. In addition, hexazinone is sensitive to soil texture, and rates may need to be increased on sites with fine-textured soils (Michael 1984, Gonzalez 1985). Another consideration is the sulfometuron application rate. The rate used in this study was less than the current recommended rate of 0.13 kg ai / ha (2 oz / acre product). Increasing sulfometuron to the recommended rate may allow a reduction in the hexazinone rate. On the other hand, hexazinone is less expensive than sulfometuron and it could prove more economical to use 0.10 kg ai/ha sulfometuron with 0.56 kg ai/ha hexazinone rather than increasing concentrations of sulfometuron and decreasing the hexazinone rate.

Controlling the herbaceous competition, either with or without hexazinone, clearly improved loblolly seedling survival, height and diameter growth. Other studies have also shown that early herbaceous weed control stimulates pine seedling survival and growth (Nelson and others 1981, Knowe and others 1985, Zutter and others 1986, Creighton and others 1987). Applying sulfometuron or sulfometuron-hexazinone mixtures resulted in increased height growth from about 12 cm to more than 40 cm at the end of two growing seasons after treatment. Early gld growth increases over untreated seedlings ranged from about 2 mm to more than 7 mm following the second growing season after treatment.

Addition of hexazinone resulted in greater height growth two growing seasons after treatment for five of the hexazinone rates and greater diameter growth for the four middle hexazinone rates. These results show that adding hexazinone at rates ranging from 0.37 to 0.84 kg ai/ha to 0.10 kg ai/ha sulfometuron stimulated height and diameter growth relative to sulfometuron with no hexazinone. The question, then, is whether or not the increased early growth observed with hexazinone-sulfometuron mixtures justifies the additional expense of hexazinone.

Economic evaluation of treatments. The true economic value of the selected treatments cannot be assessed after only 2 years. Long-term economic evaluations of herbicide treatments are lacking; however, growth and yield models have projected that increased early growth could allow earlier thinning and reduce the rotation length, improving stand economics (Minogue and others 1991, Busby 1992). Earlier thinning could provide an early return on investment and shortening the rotation length reduces the length of time investments in the stand must be carried. These factors weigh heavily in the final economic evaluation of any treatment. An evaluation of the initial herbicide costs and early growth resulting from investment in these herbicides could provide valuable information as to the level of investment in sulfometuron and hexazinone necessary to produce the desired growth response. The following evaluation cannot be considered as the final indicator of the economic value of the individual treatments, but it serves to highlight the cost and the early growth resulting from the treatments studied.

Herbicide cost for the selected treatments ranged from $5.31 /ha for sulfometuron with no hexazinone to $13.60/ha for 1.12 kg ai/ha hexazinone mixed with 0.10 kg ai/ha sulfometuron (table 3). Growth, both height and diameter, per herbicide dollar was greatest for sulfometuron alone, even though this treatment produced the least height and diameter growth of all treated plots two growing seasons after treatment. Hexazinone at rates of 0.56, 0.37 and 0.28 kg ai/ha showed similar height and diameter growth per dollar (table 3). Once the hexazinone rate exceeded 0.56, growth per dollar began to decline and the least growth per dollar was observed for 1.12 kg ai / ha hexazinone plus 0.10 kg ai/ha sulfometuron.

Conclusions

Survival was improved by all levels of herbaceous weed control. There was no gain in survival by adding hexazinone, and survival did not increase with increased rates of hexazinone. Addition of 1.12 kg ai/ha hexazinone decreased survival, indicating that this level of hexazinone may be harmful to newly planted loblolly pine seedlings.

The optimal rate of hexazinone to include with 0.10 kg ai/ha sulfometuron was 0.84 kg ai/ha based on site conditions prevalent in this study. However, the 0.56 kg ai / ha rate may be more appropriate operationally given that growth was similar from 0.56 kg ai/ha to 0.84 kg ai/ha and the cost of the 0.56 kg ai/ha treatment was less. Factors such as soil type, site index, and the amount and type of herbaceous and woody competition need also be considered when determining the optimal rates of hexazinone and sulfometuron necessary to produce the desired growth response.

Sulfometuron with no hexazinone was the least expensive treatment and produced the most growth

Table 3-Height and gronndline diameter growth two growing seasons after treatment per dollar spent off *herbicide (total height or diameter growth per herbicide cost)*

Pesticide treatment (kg ai/ha)			Height	gld
Hexazinone	Sulfometuron	Cost ($/ha)	(cm/$`ha^{-1})	(mm/$*ha^{-1})
1.12	0.10	13.60	5.13d	1.34d
0.84	0.10	11.53	8.21 c	1.72 c
0.75	0.10	10.88	8.44 c	1.82 c
0.56	0.10	9.46	9.96 b	2.07 be
0.37	0.10	7.87	10.94 b	2.43 b
0.28	0.10	7.38	10.44 b	2.21 b
0.0	0.10	5.31	12.31 a	2.88 a

Note: Means within a column sharing a letter are not significantly different (Duncan's multiple range test. P #0.05).

per dollar spent on herbicide, although this treatment showed the least total height and diameter growth of all the treated seedlings. Long-term evaluation to determine whether the early seedling growth response seen with the addition of hexazinone improved stand economics sufficiently to justify the added expense would be useful.

Address correspondence to J.L. Yeiser, University of Arkansas School of Forest Resources, Box 3468, Monticello, AR 71656.

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