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First-Year Survival and Growth of Loblolly Pine Seedlings Released From Perennial Weeds in Old Fields of Northeastern Arkansas

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Selected herbicide mixtures were assessed for controlling perennial weeds in old pastures and enhancing the growth of recently planted loblolly pine (Pinus taeda L.). *Bareroot seedlings planted in February 1990 near Batesville, Arkansas, were released from herbaceous perennial weeds with herbicides in April 1990. After one growing season, seedling mortality was 18% in treated and 30% in untreated plots. Seedling height was less responsive to weed control than diameter, with both attributes less responsive than expected, possibly because soils were compacted from previous land uses. Most herbicide mixtures studied offered similar weed control, pine tolerance, and seedling growth. Relative stem biomass per dollar of herbicide was greatest for sulfometuron + hexazinone (0.04 + 0.22 kg active ingredient per treated hectare).* Tree Planters' Notes 44(1):25-32; 1993.

Privately owned hardwood forests, primarily of the oak-hickory type, are predominant in the Ozark region of Arkansas (Hines 1988). Since 1978, there has been a 10% increase in timberland acreage in this region, with at least 95% of this increase from pasture and cropland conversion (Hives 1988). Planting old fields with loblolly pine *(Pinus taeda* L.) is attractive because it is a fast-growing, high-quality species whose planting is often cost-shared through Federal programs such as the Forestry Incentive, Conservation Reserve, and Stewardship Incentive Programs.

Most research documenting the negative impacts of herbaceous competition has involved previously forested coastal plain sites that were prepared for planting. Herbicide treatments commonly used on these sites may not be adequate when establishing pine on old-field sites in northeastern Arkansas. Sulfometuron (Oust®) and sulfometuron + hexazinone (Velpar® L) are commonly used in young pine plantations (Cantrell et al. 1985). These are effective herbicides, but other herbicide mixes show promise for controlling herbaceous weeds. Recent work on old-field sites in Georgia and South Carolina indicated that sulfometuron + imazapyr (Arsenal® AC) can effectively repress johnsongrass *(Sorghum halepense* (L.) Pers.) and bermudagrass *(Cynodon dactylon* (L.) Pers.) (Edwards and Dougherty 1988, Edwards et al. 1990, Nelson and Franklin 1990), but efficacy has not been documented for many common perennial weeds in Arkansas.

Data documenting pine response to control of perennial weeds for old-field sites within northeastern Arkansas are limited. Furthermore, herbaceous weed control efficacy and the resulting pine growth and biomass production following application of tank mixes containing combinations of sulfometuron, hexazinone, and imazapyr have not been studied. Consequently, a study was established on an old field in northeastern Arkansas to assess the potential of selected herbicide treatments for (1) pine seedling injury and growth resulting from individual applications of herbicides (index treatments); (2) controlling unwanted perennial weeds common to old pastures; and (3) enhancing the growth of newly planted loblolly pine seedlings by release from competition with selected operational tank mixes.

Methods

Study site. The study was established on an old-field site in the Ozark Mountains on the Livestock and Forestry Branch of the Arkansas Agricultural Experiment Station, near Batesville in Independence County. This site typifies old fields located in northern Arkansas that are candidates for conversion to forest. The soil was a Gepp very cherty silt loam, well drained and low in natural fertility (Ferguson et al. 1982). Rattail fescue *(Vulpia myuros* (L.) C. Gmelin), a perennial grass, and goldenrod *(Solidago* spp.*)*, a perennial broadleaf weed, were visually assessed prior to treatment as evenly distributed across all plots and suitable for testing. Other plants growing in the field but not suitable for testing were winged (also shining or dwarf) sumac *(Rhus copallina* L.), broomsedge, foxtail grass *(Setaria* spp.), miscellaneous sedges *(Carex* spp.) and beaked panicgrass *(Panicum anceps* Michaux).

Loblolly seedlings were hand-planted in February 1990 on a 1.8 x 3.6 m spacing. The planting stock was genetically improved first-generation seed orchard, 1+0 bareroot seedlings obtained from the Arkansas Forestry Commission's Baucum Nursery in Little Rock. At the time of herbicide application late in April 1990, fescue was 15 to 20 cm tall, goldenrod was 20 to 25 cm tall, and pine seedlings averaged 25.9 cm tall and had recently flushed 1.27 cm.

Study layout. The study was established as a randomized complete block with 3 blocks and 12 treatments per block. Plots were 1.2 x 33 m, surrounded by 1.2-m buffers, and centered over 18 loblolly pine seedlings spaced evenly at 1.8-m intervals throughout the plot.

Of the 12 treatments, 1 was an untreated control, 4 were index treatments, and 7 were operational treatments. Index treatments received single applications of one herbicide in April 1990 followed by additional applications in June and August 1990 of 3% glyphosate (Roundup®) in water solution (table 1). Seedlings in index plots were shielded from the glyphosate spray to prevent death or injury to actively growing pine seedlings (Cantrell et al. 1985). Weeds growing at the base of seedlings were removed by hand. The seven operational treatments received a one-time application of herbicide in April 1990 (table 1). A single herbicide application is typical of weed control practiced in young loblolly pine stands (Minogue et al. 1991). Herbicide applications were made over the top of seedlings at 140.3 liters/ha (15 gallons per acre) with a 2-nozzle, hand-held spray boom equipped with flat-fan nozzle tips.

Untreated control plots show the impact of herbaceous competition on seedling survival and growth. In contrast, total vegetation control achieved with the index treatments illustrates the growth and seedling injury resulting from herbicide treatments without the confounding effects of competition, thus enabling us to determine whether growth inhibitions were significant. Operational treatments allow determination of the growth response to weed control provided by each of the tank mixes studied.

Evaluations. Control of fescue and goldenrod, percentage bare ground, and pine seedling injury were recorded 60 and 120 days after treatment (DAT) in each plot relative to the untreated check. Control of fescue and goldenrod plus bare ground estimates were visually ranked in 10% classes, with 0% indicating no control and 100% total control. Percentage bare ground was an estimation of plot area not covered by live herbaceous plants. Pine seedling injury was evaluated in 10% classes so that 0% indicated a healthy seedling with terminal elongation, 30% a stunted seedling, 50% a completely chlorotic seedling, and 100% a dead seedling.

Initial stem height (centimeters) and diameter (centimeters) were measured in February 1990, immediately after planting. First-year stem height, diameter, and survival were recorded on all seed lings in early December 1990. Seedling height was measured with a ruler from groundline to the apex of the terminal bud, and stem diameter was measured with vernier calipers at groundline.

In early December 1990, all surviving pines were carefully dug from the ground. Seedlings were brought back to the laboratory where they were washed free of soil and dissected into roots, needles, stems, and branches. These biomass components were ovendried and their weights measured on a balance scale to the nearest 0.01 g.

Data analysis. Before analysis, percentage values for fescue and goldenrod control, bare ground, pine injury, and seedling survival were transformed with $\arcsin\sqrt{\%}$ (Steel and Torrie 1980). A stem biomass /herbicide cost ratio was developed to assess wood fiber gains over herbicide cost per hectare-weight of stem biomass component (kilograms per hectare) /herbicide cost (dollars per hectare). Analysis of variance was used to test data (SAS Institute 1988), and means were separated with Tukey's studentized range test (a = 0.05). Untransformed values are presented in this paper.

Results and Discussion

Visual plot evaluations. Control of perennial weeds and percentage bare ground were comparable among operational treatments (table 2). Goldenrod was easily controlled by operational treatments averaging 91% 60 DAT and 85% 120

Table 1 -*Herbicide treatments for perennial weed control applied in late April 1990 near Batesville, Arkansas*

	Application rate*					
	Sulfometuron		Imazapyr		Hexazinone	
Herbicide treatment	ai	product	ai	product	ai	product
Untreated control	-	-	-	-	-	-
Index†						
Sulfometuron	0.08	0.15	-	-	-	-
Hexazinone	-	-	-	-	0.67	3.50
Imazapyr	-	-	0.168	0.44	-	-
Imazapyr	-	-	0.279	0.73	-	-
Operational‡						
Sulfometuron + imazapyr	0.04	0.07	0.112	0.29	-	-
Sulfometuron + imazapyr	0.08	0.15	0.056	0.15	-	-
Sulfometuron + imazapyr	0.08	0.15	0.112	0.29	-	-
Sulfometuron + imazapyr + hexazinone	0.04	0.07	0.056	0.15	0.22	1.17
Sulfometuron + hexazinone	0.04	0.07	-	-	0.22	1.17
Sulfometuron + hexazinone	0.08	0.15	-	-	0.45	2.34
Imazapyr	-	-	0.168	-	-	-

*ai = kilograms of active ingredient per hectare (kg ai/ha); product = liters of product per treated hectare (I/ha). [To convert kilograms ai per hectare to pounds ai per acre, multiply by 1.12. To convert liters per hectare to ounces per acre, multiply by 13.7.] All herbicide treatments were mixed with water and applied at 140.3 I/ha (15 gallons per acre).

†Total vegetation control was maintained with subsequent directed applications of a 3% solution of glyphosate in water at 60 and 120 days after treatment.

‡Single over-the-top application of herbicide.

averaged 85% 60 DAT and decreased to 68% 120 DAT. Also, percentage bare ground 60 DAT averaged 88% and decreased to 53% 120 DAT. As expected, index treatments effectively controlled herbaceous competitors throughout the duration of the study with goldenrod control, fescue control, and bare ground averaging 97% 120 DAT.

Based on evaluation of index treatments, individual herbicides did not substantially injure seedlings either 60 or 120 DAT. The greatest seedling injury (22%) was observed with imazapyr (0.279), which showed double the seedling injury of imazapyr (0.168) at 120 DAT (table 2). For operational treatments, seedling injury 60 DAT averaged 6% and was greatest in plots treated with sulfometuron + hexazinone (0.08 + 0.45) (table 2). Seedling injury 120 DAT was 26% for sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22) and was 22% for sulfometuron + hexazinone (0.08 + 0.45) (table 2). Hexazinone is soil active, labeled for use at the rates studied, and has demonstrated its safety when used to release pine seedlings from perennial grasses in pastures in the coastal plain of southwestern Arkansas (Yeiser and Boyd 1989). The unexpected damage may be related to the fact that 0.45 kg ai/ha is at the upper end of labeled rates and that a recent flush provided soft, juvenile tissue, which is highly susceptible to injury. Greater injury resulted from the three-way mixture of sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22) versus either rate of sulfometuron + hexazinone alone. This, in conjunction with injury observed for the individual herbicides, indicates that the mixture of sulfometuron + imazapyr + hexazinone was antagonistic to seedling development.

Pine mortality and growth. Pine seedling mortality averaged 19% across plots receiving an operational herbicide treatment, 16.5% for index treatments, and 30% on control plots (table 3). Greatest mortality on an operationally treated plot resulted from application of sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22). This same mixture also showed the greatest visual injury to seedlings (tables 2 and 3). Least mortality occurred on the index plot treated with imazapyr (0.168) and although all treated plots showed greater survival than the untreated check, this was the only treatment with statistically greater survival (table 3).

Only the sulfometuron (0.08) index treatment produced seedlings with significantly greater heights than the controls (table 3). Greatest total height for operational treatments occurred on plots treated with sulfometuron + hexazinone (0.04 + 0.22, 0.08 + 0.45), both of which exceeded control heights by more than 5 cm. Sulfometuron + imazapyr (0.04 + 0.112) plots showed height growth

Table 2-*Visual evaluations of percentage control of goldenrod and fescue, percentage bare ground, and percentage pine injury 60 and 120 days after treatment (DAT) in late April 1990 near Batesville, Arkansas*

	Percent reduction			
Herbicide treatment (kg ai/ha)	Goldenrod	Fescue	Bare Ground	Injury
60 days after treatment				
Index*				
Sulfometuron (0.08)	98 a	98 a	98 a	8 ab
Hexazinone (0.67)	98 a	98 a	98 a	16 a
Imazapyr (0.168)	98 a	98 a	98 a	2 b
Imazapyr (0.279)	98 a	98 a	98 a	8 ab
Mean	98	98	98	9
Operational†				
Sulfometuron + hexazinone (0.04 + 0.22)	87 b	73 b	77 b	7 ab
Sulfometuron + imazapyr (0.04 + 0.112)	92 ab	90 ab	90 ab	7 ab
Sulfometuron + hexazinone (0.08 + 0.45)	93 ab	90 ab	90 ab	11 a
Sulfometuron + imazapyr (0.08 + 0.056)	92 ab	88 ab	90 ab	2 b
Sulfometuron + imazapyr (0.08 + 0.112)	98 a	95 ab	90 ab	8 ab
Sulf + imaz + hex (0.04 + 0.056 + 0.22)	92 ab	73 b	87 ab	6 ab
Imazapyr (0.168)	88 ab	83 b	90 ab	2 b
Mean	91	85	88	6
120 days after treatment				
Index*				
Sulfometuron (0.08)	97 a	97 a	97 a	15 ab
Hexazinone (0.67)	98 a	97 a	98 a	18 ab
Imazapyr (0.168)	97 a	97 a	97 a	11 b
Imazapyr (0.279)	97 a	97 a	97 a	22 ab
Mean	97	97	97	16
Operational†				
Sulfometuron + hexazinone (0.04 + 0.22)	80 c	57 c	43 c	18 ab
Sulfometuron + imazapyr (0.04 + 0.112)	92 abc	70 b	53 b	18 ab
Sulfometuron + hexazinone (0.08 + 0.45)	80 c	73 b	60 b	22 ab
Sulfometuron + imazapyr (0.08 + 0.056)	83 bc	67 bc	47 bc	15 ab
Sulfometuron + imazapyr (0.08 + 0.112)	87 abc	77 ab	68 ab	18 ab
Sulf + imaz + hex (0.04 + 0.056 + 0.22)	83 bc	63 bc	43 c	26 a
Imazapyr(0.168)	90 abc	67 bc	57 b	15 ab
Mean	85	68	53	19

See table 1 for conversion of kilograms ai per hectare to pounds ai per acre. Means in a column sharing the same letter do not differ significantly (Tukey's studentized range test, " = 0.05).

*Index treatments. Total vegetation control was maintained in these plots with subsequent directed applications of a 3% glyphosate in water solution at 60 and 120 days after treatment.

†Single over-the-top application of herbicide.

approximately 4 cm greater than controls (table 3). Among index treatments, those seedlings treated with imazapyr (0.279) were nearly 4 cm shorter than control seedlings and imazapyr (0.168) seedlings did not substantially exceed heights observed for control plots (table 3).

Groundline diameter was significantly greater than control seedlings for all treatments except sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22) (table 3). Among operational treatments, diameter was greatest for seedlings receiving sulfometuron + imazapyr (0.08 + 0.056) and sulfometuron + hexazinone (0.08 + 0.112), although diameter growth did not substantially differ among operational treatments (table 3). Imazapyr (0.279) showed the least and sulfometuron (0.08) the greatest diameter growth among index treatments, though diameter growth was not substantially different among index treatments (table 3).

Although statistical significance is lacking for height data, height results appear to be biologically pertinent. When height is examined relative to the controls, it is clear that most tank mixes studied had a positive impact on early growth of loblolly seedlings. Lack of statistical significance is probably the result of lack of precision in the experiment due in part to underestimation of the sample size appropriate for the site.

Examination of the index treatment data revealed that the individual herbicides, with the possible ex-

Table *3-Mortality, total height, and gronndline diameter of pine seedlings one growing season after treatment for perennial herbaceous weeds near Batesville Arlransas.*

Herbicide treatment (kg ai/ha)	Mortality (%)	Height (cm)	Diameter (cm)
Initial			
First year	0	20.09	0.36
Index*			
Sulfometuron (0.08)	15 ab	49.53 a	0.99 a
Hexazinone (0.67)	18 ab	41.76 abc	0.81 ab
Imazapyr (0.168)	11 a	38.68 bc	0.84 ab
Imazapyr (0.279)	22 ab	34.70 c	0.76 b
Mean	16.5	41.17	0.86
Operationalt			
Sulfometuron + hexazinone (0.04 + 0.22)	18 ab	43.87 ab	0.76 b
Sulfometuron + imazapyr (0.04 + 0.112)	18 ab	42.95 abc	0.76 b
Sulfometuron + hexazinone (0.08 + 0.45)	22 ab	44.07 ab	0.81 ab
Sulfometuron + imazapyr (0.08 + 0.056)	15 ab	36.80 bc	0.84 ab
Sulfometuron + imazapyr (0.08 + 0.112)	18 ab	38.58 bc	0.74 b
Sulf + imaz + hex (0.04 + 0.056 + 0.22)	26 b	37.19 bc	0.66 bc
Imazapyr (0.168)	15 ab	37.57 bc	0.69 b
Mean	18.9	40.16	0.76
Control	30 b	38.66 bc	0.48 c

See table 1 for conversion of kilograms ai per hectare to pounds per acre. Means in a column sharing the same letter do not differ significantly (Tukey's studentized range test, " = 0.05).

*Index check treatments. Total vegetation control was maintained in these plots with subsequent directed applications of a 3 % glyphosate in water solution at 60 and 120 days after treatment.

†Single over-the-top application of herbicide.

ception of imazapyr (0.279), did not stunt seedling growth nor did they increase seedling mortality (table 3). In the operational treatments, where vegetation was allowed to reinvade plots, mortality was comparable and growth equaled or exceeded that observed for the controls. Only the three-way mix of sulfometuron + imazapyr + hexazinone appeared to have any negative impact on seedling development.

On the other hand, relative to the seedlings in the controls, operational treatments did not produce the amount of positive response in height and diameter growth expected based on loblolly response to herbicide release reported by other authors (Creighton et al. 1987, Haywood and Tiarks 1981, Holt et al. 1973, Knowe et al. 1985, Nelson et al. 1981, Yeiser and Boyd 1989, Zutter et al. 1986). This suggests that factors other than competition may have inhibited the early response of newly planted seedlings. Soil moisture should not have been a limiting factor, although precipitation for the summer months (June-September) of 1990 was nearly 13 cm below normal, because controlling vegetation improves soil moisture availability to pine seedlings (Mitchell et al. 1991). Soil fertility may have been a factor, although fertility at this site is typical of most sites in northern Arkansas. Soils at the site were, however, highly compacted from previous agricultural practices and this compaction was probably the primary factor limiting seedling growth response to herbicide release. Managers should weigh the advantages of mechanical soil treatment, such as ripping, for reducing compaction in addition to vegetation management when planting pine on old field sites.

It was also apparent that height was less responsive to control of herbaceous weeds than ground line diameter (table 3). Seedlings in 4 of 7 operational treatments and 1 index treatment exhibited lower mean height than the controls (table 3). Based on the average of the index and operational treatments, heights of seedlings in treated plots exceeded the controls by about 5% (table 3). Diameter growth was greater for all treated plots versus the untreated check and exceeded the untreated check by nearly 70% (table 3). Zutter et al. (1986) observed similar trends in a study of height and diameter growth in relation to herbaceous competition on an Upper Coastal Plain site in Alabama.

Pine biomass. As was the case with growth analyses, a lack of precision in this experiment resulted in an apparent lack of statistical significance for biomass data. In spite of the lack of statistical evidence, we believe that differences in biomass production in treated versus untreated seedlings are biologically significant.

Root development was greater for all index treatments and operational treatments versus the untreated controls, although only sulfometuron (0.08) statistically increased root development (table 4). Sulfometuron is a mitotic inhibitor, and Barnes et al. (1989) found that it stunted root growth potential in loblolly pine seedlings. Yeiser and Barnett (1991) suspected that roots of shortleaf pine *(Pinus echinata .)* grown on a ripped site and treated with sulfometuron may have initially been stunted, but demonstrated that benefits from herbaceous weed control outweighed any initial stunting. In this abandoned field, we found no significant differences in root development among the index plots (table 4). For operational herbicide treatments, root systems for seedlings treated with sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22)showed the smallest average root biomass (table 4).

Pine seedling needle biomass was influenced by herbicide treatment and interfering vegetation (table 4). Six treatments (3 index treatments and 3 operational treatments) yielded seedlings with significantly greater needle biomass than those grown under herbaceous competition (table 4). Needle biomass was at least 3 times greater for all treatments except sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22), which still produced more than 2 times greater needle biomass than the untreated check (table 4).

First-year branch development was minimal for all treatments, as branches were the smallest com ponent of total seedling biomass (about 7%) (table 4). Controlling herbaceous weeds around the pine seedlings did not influence first-year branch development.

Herbaceous competitors and herbicide treatment influenced stem biomass (table 4). All index and operational treatments produced mean stem biomass greater than the control treatment did and, in all but one case, stem biomass was at least 2 times more than that observed for the controls (table 4). Three index treatments and 4 operational treatments yielded seedlings with statistically greater stem biomass than controls (table 4). The addition of imazapyr to a sulfometuron + hexazinone (0.04 + 0.22) tank mix significantly reduced stem bio mass yields. Including imazapyr in a sulfometuron + hexazinone tank mix could hypothetically increase the control spectrum for perennial weeds. However, the visible pine damage, inhibited height growth, and significantly lower stem biomass yields indicated that over-the-top application of this tank mix harmed the pine seedlings.

Reducing herbaceous competition with herbicides generally increased total pine seedling biomass (table 4). All index and operational treatments produced substantially more seedling biomass than untreated check seedlings (table 4). Although all operational treatments produced statistically similar biomass, the sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22) treatment produced

Table 4-*Mean weights for components of seedling biomass one growing season after treatment for perennial herbaceous weeds near Batesville, Arkansas*

Herbicide treatment (kg ai/ha)	Weight (g)				
	Root	Needle	Branch	Stem	Total
Index*					
Sulfometuron (0.08)	13.61 a	14.46 a	2.55 a	8.51 a	39.12 a
Hexazinone (0.67)	8.22 ab	10.77 ab	2.27 a	5.67 abc	27.22 ab
Imazapyr (0.168)	8.51 ab	10.49 ab	1.98 a	5.39 abc	26.37 ab
Imazapyr (0.279)	6.24 ab	7.37 abc	1.98 a	4.25 bcd	19.85 abc
Operational†					
Sulfometuron + hexazinone (0.08 + 0.45)	7.65 ab	10.21 ab	2.55 a	5.10 abc	25.52 ab
Sulfometuron + imazapyr (0.04 + 0.112)	6.80 ab	8.79 ab	1.70 a	5.39 abc	22.68 abc
Sulfometuron + hexazinone (0.04 + 0.22)	6.52 ab	6.52 abc	1.13 a	6.52 ab	20.70 abc
Sulfometuron + imazapyr (0.08 + 0.056)	6.24 ab	8.22 ab	1.42 a	5.39 abc	21.26 abc
Imazapyr (0.168)	5.10 ab	7.37 abc	1.13 a	4.54 abcd	18.41 abc
Sulfometuron + imazapyr (0.08 + 0.112)	6.24 ab	7.37 abc	1.13 a	3.97 bcd	18.71 abc
Sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22)	4.25 b	4.82 bc	1.13 a	2.84 cd	13.04 bc
Control	2.27 b	2.27 c	0.85 a	1.98 d	7.37 c

See table 1 for conversion of kilograms ai per hectare to pounds per acre. Means in a column sharing the same letter do not differ significantly (Tukey's studentized range test, " = 0.05).

*Index treatments. Total vegetation control was maintained in these plots with subsequent directed applications of a 3 % glyphosate in water solution at 60 and 120 days after treatment.

†Single over-the-top application of herbicide.

substantially less biomass than the other operational treatments (table 4). The sulfometuron + hexazinone (0.08 + 0.45) treatment was the only operational application that yielded statistically more total seedling biomass than did the control treatment (table 4). Three of the four index treatments yielded significantly greater biomass than controls, the exception being imazapyr (0.279) (table 4). Sulfometuron (0.08) produced the greatest biomass of the index treatments, with total biomass exceeding the imazapyr (0.279) index treatment by nearly 20 g/ha and exceeding control values by nearly 33 g/ha (table 4).

Biomass/cost ratio. Since many of the operational treatments provided similar herbaceous weed control and pine growth, a ratio of first-year stem biomass produced versus the cost for each treatment would be beneficial to the manager selecting an herbicide treatment. The approximate costs per hectare for herbicide ranged from $5.70 to $11.40 (table 5). Sulfometuron + hexazinone (0.08 + 0.45) produced the greatest biomass per dollar spent, although several other operational treatments produced statistically similar ratios (table 5). This ratio is not to be confused with cost effectiveness, which is determined at the end of the rotation and influenced by timely intermediate treatments such as thinning.

Table 5—*Relative first-year stem biomass per hectare, approximate herbicide cost per hectare and biomass/cost ratio of one-time operational herbicide applications for perennial weed control near Batesville, Arkansas*

Herbicide treatment (kg ai/ha)	Stem biomass (kg/ha)	Cost ($/ha)*	Biomass: cost ratio†
Sulfometuron + hexazinone (0.04 + 0.22)	7.53	5.70	1.32 a
Sulfometuron + imazapyr (0.04 + 0.112)	5.70	7.13	0.80 ab
Sulfometuron + imazapyr (0.08 + 0.056)	4.07	8.42	0.48 ab
Imazapyr (0.168)	4.02	5.83	0.69 ab
Sulfometuron + hexazinone (0.08 + 0.45)	5.15	11.40	0.45 ab
Sulfometuron + imazapyr (0.08 + 0.112)	3.28	10.36	0.32 ab
Sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22)	1.46	7.64	0.19 b

See table 1 for conversion of kilograms ai per hectare to pounds per acre.
Means in a column sharing the same letter do not differ significantly (Tukey's studentized range test, $\alpha = 0.05$).
*Cost of herbicide treatment per hectare (cost per acre = cost per hectare times 2.47); 1990 herbicide prices were used for relative comparison.
†Biomass/cost ratio is stem biomass per hectare/herbicide cost per hectare.

Conclusions

Seedling injury and mortality were less and height and diameter growth greater for most index treatments versus the controls. These results indicate that application of the individual herbicides studied did not stunt growth or otherwise interfere with loblolly seedling development independent of effects associated with herbaceous competition. It is apparent, however, that over-the-top application of the mixture that combined sulfometuron, imazapyr, and hexazinone harmed newly planted pine much more than other operational treatments.

Because most operational treatments provided similar growth and biomass yields with similar weed control and minimal visible seedling damage, economic considerations could be a major factor when selecting an herbicide for seedling release. For establishing loblolly pine on this old-field site, sulfometuron + hexazinone (0.04 + 0.22) yielded greatest first-year stem biomass per unit cost of herbicide.

Managers should carefully assess sites for herbaceous competition, soil compaction, and other conditions that may restrict growth and impose the combination of treatments, chemical and mechanical, that will insure a positive growth response for establishment of loblolly pine in old fields.

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