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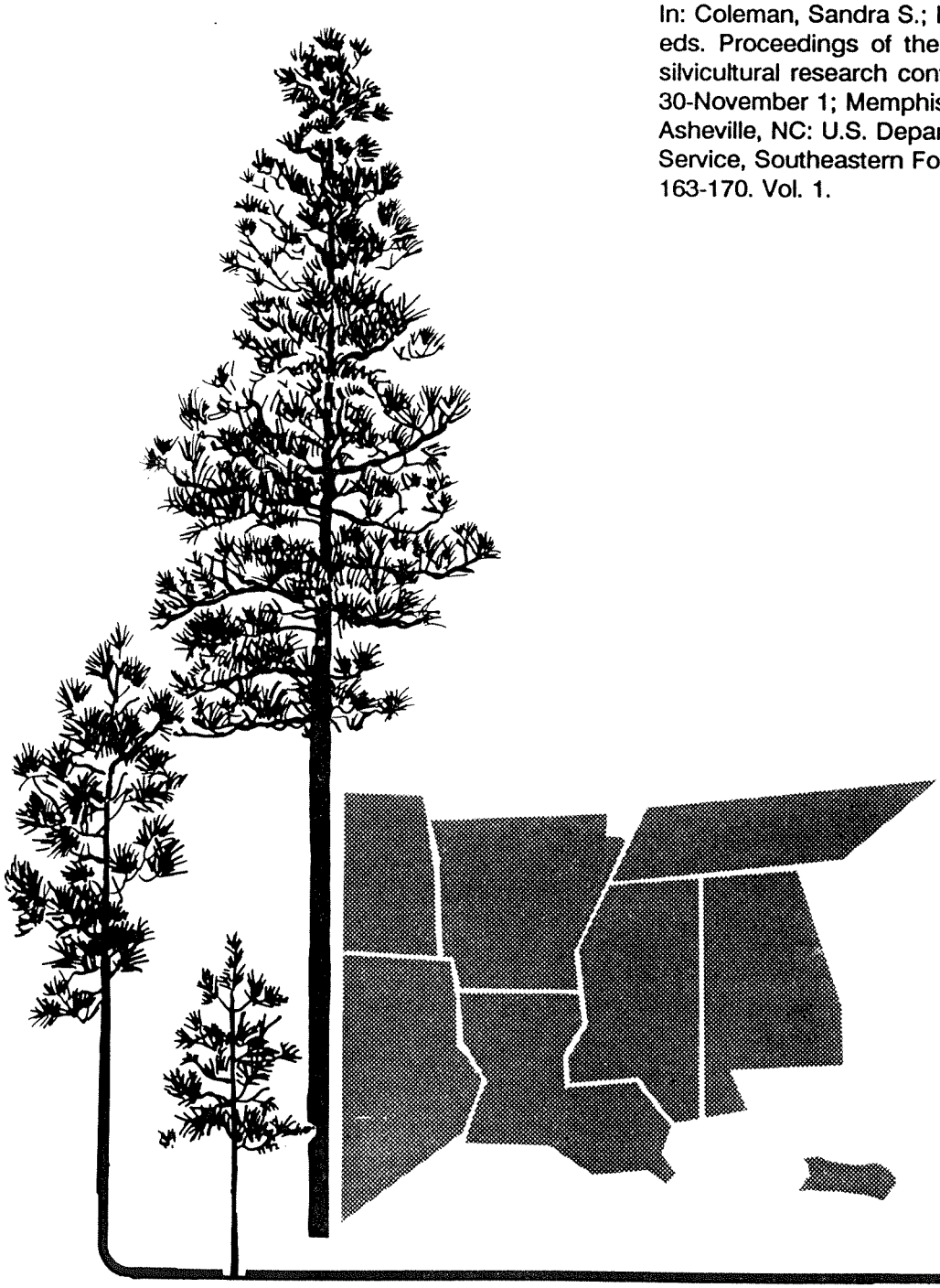

Southern Forest Experiment Station

TOLERANCE OF LOBLOLLY PINE SEEDLINGS TO GLYPHOSATE [1]

James D. Haywood and Thomas W. Melder [2]

Abstract. Broadcasting glyphosate herbicide over loblolly pine (*Pinus taeda* L.) may provide enough early-season weed control to allow seedlings to establish themselves more rapidly, but glyphosate can injure young trees. To examine the question of seedling injury, four rates of glyphosate were broadcast evenly over planted loblolly pine seedlings, competing vegetation, and plot surface. The rates were 0.42, 0.84, 1.26, and 1.68 kg acid equivalent per hectare (1 pt, 1 qt, 1.5 qt, and 2 qt Roundup™ herbicide per acre). Treatments were made on six separate dates, from April 23 through October 14, of the first growing season. Although glyphosate effectively controlled competing vegetation, all treatments injured the pine seedlings and reduced height growth, and many treatments increased pine mortality.

Introduction

Controlling herbaceous competitors in young loblolly pine plantations can increase seedling survival, pine diameter, and height growth (Nelson et al., 1981; Creighton et al., 1987; Haywood and Tiarks 1990). Weed control may be especially important when converting pasture to pine stands (Haywood 1988; Yeiser et al., 1987). The application of herbicides is often the best method of controlling weeds on forest sites. However, forest managers still lack sufficient information about which herbicide to use and the best dates and rates of application.

Glyphosate herbicide, N-(phosphonomethyl)glycine, is labeled for forestry and is also widely used in agriculture and landscaping and on industrial sites. Glyphosate is usually applied in the fall as a release treatment in pine plantations. Because the year's growing season is almost over, its immediate benefit as a weed control agent is minimal. Because glyphosate is not soil active, it provides no residual weed control the next spring (Haywood 1988). Applying glyphosate earlier in the growing season is a better weed control strategy, but how much seedling injury may result?

To examine the question of seedling injury, four rates of glyphosate, 0.42, 0.84, 1.26, and 1.68 kg acid equivalent per hectare (kg ae/ha) (1 pt, 1, 1.5, and 2 qt Roundup™ herbicide/ac), were broadcast evenly over planted loblolly pine seedlings and competing vegetation. Treatments were made on six dates, from April 23 through October 14 of the first growing season. For

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comparison purposes, the labeled rates of glyphosate range from 0.42 to 0.63 kg ae/ha when in tank mixture with sulfometuron methyl for herbaceous weed control and from 1.26 to 1.68 kg ae/ha when applied alone for loblolly pine release in the fall.

Methods

Study Establishment

The study was duplicated on two sites. Site one was a Beauregard silt loam (Plinthaquic, Paleudult, fine-silty, siliceous, thermic) at the J.K. Johnson Tract, Palustris Experimental Forest, Sec. 4, T2N, R3W, Rapides Parish, Louisiana. Site two was a Kolin silt loam (Glossaquic Paleudalf, fine-silty, siliceous, thermic) on the Kisatchie National Forest, Evangeline Ranger District, Compartment 45, Sec. 31, T2N, R2W, Rapides Parish, Louisiana. Both were gently sloping (1-3 percent), moderately well-drained upland sites, but the sites had different cover conditions because of their different management histories.

Site one supported a stand of slash pine (*Pinus elliotii* Engelm. var. *elliotii*). This stand was clearcut in 1973, and the residual trees and logging debris were single chopped with a rolling drum chopper. The vegetation was unrestrained except for periodic controlled burns to reduce fire hazards. Because of burning, vegetation at site one was primarily a heavy rough of bluestem and panicum (*Andropogon* spp. and *Panicum* spp.) grasses, broadleaf weeds (*Rubus* spp.), and scattered sprouts of several typical hardwood species (*Myrica cerifera* L., *Rhus copallina* L., and *Liquidambar styraciflua* L.) at the time of establishment.

Site two was grazed by cattle and supported a stand of loblolly pine (*Pinus taeda* L.). This stand was clearcut in 1980, and the residual trees and logging debris were single chopped with a rolling drum chopper and control burned that fall. Grazing continued, and the vegetation was primarily a low cover of common carpet grass (*Axonopus affinis* Chase), other grasses, broadleaf weeds, and scattered sprouts of several typical hardwood species at the time of establishment.

In January 1982, at both sites, 2-m^2 plots were established in a randomized complete block design with seven blocks. Each block had 30 plots. Plot centers were located on a 3- by 3-m spacing. On each plot, two 1-0 bareroot loblolly pine seedlings were planted about 30-cm apart in the center of the plot. Blocks were established because of site variation and to simplify treatment installation and measurement.

Treatments

Glyphosate in a water solution of 235 L/ha (25 gal/ac) was broadcast evenly over the pine seedlings, competing vegetation, and plot surface. Glyphosate was applied with a hand-pump sprayer. A plastic-lined cylinder was used to delineate the plot perimeter and to prevent drift. At both sites, four concentrations of glyphosate (0.42, 0.84, 1.26, and 1.68 kg ae/ha) were applied on each of the following dates for comparison to untreated checks:

April 23, 1982. Continual rains delayed treatment until this date, and the soil was very wet. The sky was overcast with high clouds, but it did not rain. Winds were 8-24 km per hour (kmph) (5-15 mph). The daytime high temperature was 7°C (45°F). Treatments were finished by 11 a.m.

May 19, 1982. Pines were in active height growth. The sky was partly cloudy. Winds were 0-8 kmph (0-5 mph). Temperatures ranged from 18°C (65°F) to an afternoon high of 27°C (80°F). Treatments were finished by 11:45 a.m.

June 15, 1982. The sky was clear to partly cloudy. Winds were 8-24 kmph (5-15 mph) at site one and 0-8 kmph (0-5 mph) at site two. Temperatures ranged from 22°C (72°F) to an afternoon high of 34°C (94°F). Treatments were finished by 11:45 a.m.

July 15, 1982. The sky was clear to partly cloudy. Winds were 0-2 kmph (0-1 mph). Temperatures ranged from 24°C (75°F) to an afternoon high of 35°C (95°F). Treatments were finished by 12:20 p.m.

August 30, 1982. The sky was clear-but-hazy to partly cloudy. Winds were 0-2 kmph (0-1 mph). Temperatures ranged from 29°C (85°F) to an afternoon high of 36°C (97°F). Treatments were finished by 11:15 a.m.

October 14, 1982. The sky was clear. Winds were 0-2 kmph (0-1 mph). There was a heavy dew at site two during treatment, but no dew remained by the time site one was treated. Temperatures ranged from 16°C (60°F) to an afternoon high of 24°C (75°F). Treatments were finished by 11:30 a.m.

Measurements And Data Analysis

Before glyphosate was applied, the pine seedlings were examined to determine if the seedlings were in an active growth stage. In June 1983, seedling heights were taken to the nearest 2.5 cm, and the pines were rated as follows: (1) no evident injury; (2) some injury (0-25 percent); (3) moderate injury (26-50 percent), and; (4) severe injury (more than 50 percent). Of the original 210 plots per site, 157 plots remained at site one and 148 plots remained at site two. These plots eventually were lost because all the pines died after treatment with glyphosate.

For each site, regression analysis was used to determine the relationship among seedling survival, height, or injury rating and rate of glyphosate and date of treatment. A polynomial model with a periodic term best described these relationships within the range of observations (Bliss 1970). The general form of the function follows:

$$Y = b_0 + b_1 (Ra) + b_2(Ra^2) + b_3(D) + b_4(I) + b_5 \{\sin[\text{trans}(D)]\} + \text{error},$$

where

Y = seedling survival, height, or injury rating,
Ra = glyphosate rate,
D = Julian date,
I = rate x date interaction, and
sin[trans(D)] = a periodic sine curve relationship where date is first transformed by trans(D) = $2\pi/365$*date.

Glyphosate effectiveness as a weed control agent was determined by periodic inspection of the plots. The competing plant data were not analyzed because of the high efficacy initially obtained with all treatments and the lack of residual control inherent with glyphosate.

Results And Discussion

Pine Survival

Loblolly pine seedling survival was influenced by glyphosate rate and date of treatment (Tables 1 and 2, Fig. 1). At site one, mortality increased when glyphosate was used regardless of rate or date of application although the rates used corresponded to the labeled rates for glyphosate. However, the detrimental effect of chemical use was greater in the summer than in the spring or fall. Seedling survival was also influenced by a rate x date interaction. In the spring, the higher rates of glyphosate were estimated to reduce survival more than the lower rates, but in the fall, differences in survival among glyphosate treatments were no longer important.

At site two, seedling survival was affected by a rate x date interaction (Table 1, Fig. 1). The interaction suggests that survival was adversely influenced in the spring by glyphosate. However, by fall, survival was no longer significantly affected by chemical treatment. This relationship was not a strong one because of a 10.32-percent R^2, a 10-percent probability of a greater $|T|$-value for the interaction coefficient and the actual low number of surviving seedlings after the October treatment (Tables 1 and 2, Fig. 1).

Survival on checks was lowest at site two, possibly because the cattle grazing resulted in animal injury and the close cropped vegetation exposed the seedlings to wind and temperature extremes (Table 1). However, the greater exposure of seedlings to direct contact with glyphosate at site two than at site one apparently did not increase pine mortality when compared with the check treatments.

At both sites, pine survival was generally better after the June 15 glyphosate treatments than after the May 19 and July 15 treatments (Table 1). Unfortunately, higher survival on June 15 could not be explained based on observing the seedlings' general condition (stage of growth or vigor) when treated. Therefore, seedling condition was not useful in predicting loblolly pine survival, although the seedlings are perhaps more tolerant of glyphosate exposure during certain periods in the spring.

Pine Height And Injury

Loblolly seedling height growth and injury rating were adversely affected by glyphosate application regardless of rate (Tables 1 and 2; Fig. 2 and 3). Yeiser and others (1987) also reported reduced height growth after April applications of glyphosate in mixture with sulfometuron methyl when treating herbaceous plant covers.

At site one, estimated average seedling height was greater on the October 14 treatment date than on all other treatment dates, but height growth

Table 1. Loblolly pine seedling survival, height, and injury rating 17 months after planting.

Dates of treatment 1982	Site one Rates (kg ae/ha) None	0.42	0.84	1.26	1.68	Weighted mean	Site two Rates (kg ae/ha) None	0.42	0.84	1.26	1.68	Weighted mean
	Survival (percent)											
April 23	100	71	64	21	36	59	93	71	57	64	21	61
May 19	100	43	14	7	14	36	86	43	29	14	0	34
June 15	100	71	93	57	71	79	64	71	64	64	64	66
July 15	93	71	29	21	0	43	64	57	36	29	7	39
August 30	93	57	50	43	14	51	64	43	71	21	14	43
October 14	93	100	86	93	86	91	86	50	64	64	43	61
Weighted mean	96	69	56	40	37		76	56	54	43	25	
	Height (cm)											
April 23	61	39	30	39	35	42	51	30	27	33	42	36
May 19	55	34	20	30	24	40	47	31	21	34	..	36
June 15	65	44	42	39	39	46	36	42	37	31	36	37
July 15	46	33	34	25	..[1]	6	55	35	41	27	18	41
August 30	62	37	25	30	32	39	56	29	40	26	22	38
October 14	64	54	42	52	41	50	45	48	39	50	37	44
Weighted mean	59	41	34	39	37		49	37	35	34	35	
	Injury rating											
April 23	1.0	3.0	3.4	2.5	3.3	2.6	1.0	2.8	2.8	2.5	2.7	2.3
May 19	1.0	3.0	4.0	3.0	4.0	2.4	1.1	2.5	3.0	3.0	..	2.1
June 15	1.0	2.5	2.4	2.9	2.9	2.3	1.2	1.9	2.6	2.5	2.9	2.3
July 15	1.0	3.4	3.7	4.0	...	2.7	1.1	2.9	2.4	3.3	4.0	2.3
August 30	1.0	3.3	4.0	3.8	4.0	3.0	1.0	3.4	2.9	3.3	4.0	2.7
October 14	1.0	1.8	2.8	2.4	3.0	2.2	1.1	2.1	2.3	2.2	2.5	2.0
Weighted mean	1.0	2.8	3.2	3.1	3.2		1.1	2.5	2.6	2.7	3.0	

[1] Where values are missing, all seedlings died after treatment on all of the blocks.

was nearly completed by fall so less effect was possible (Table 1 and Fig. 2). Seedling height was most adversely affected by summer treatments. At site two, seedling height was also less after the spring treatments than after the fall treatment. The significant adverse effect associated with summer applications of glyphosate at site one was not found at site two (Table 2 and Fig. 2).

At sites one and two, seedling injury on the October 14 treatment date was less than injury on the other treatment dates, and seedling injury was greater on the summer treatment dates than on the other treatment dates (Tables 1 and 2, and Fig. 3). This finding supported the practice of applying glyphosate in the fall especially at rates greater than 0.42 kg ae/ha.

Weed Control

Glyphosate, regardless of rate, provided 95-percent or better control of the herbaceous plant cover following treatment. High efficacy was expected because in other unpublished work the herbaceous species present were shown to be susceptible to glyphosate.

Table 2. Coefficients for the independent variables and the probabilities of greater |T|-values used to predict survival, height, and injury ratings for sites one and two.

Variables	Coefficient estimate	Prob > |T|
Site One		
Survival, percentage		
Intercept	-10.6745	0.7101
Glyphosate rate	-56.2772	0.0001
(Glyphosate rate)^2	14.23633982	0.0145
Julian date	0.56449919	0.0003
Rate x date interaction)	0.08175951	0.0778
Sin[trans(date)]	48.79473952	0.0001
Height, centimeters		
Intercept	-14.0731	0.4013
Glyphosate rate	-42.7999	0.0001
(Glyphosate rate)^2	18.21129423	0.0001
Julian date	0.38041001	0.0001
Sin[trans(date)]	28.72948901	0.0002
Injury rating		
Intercept	6.02810658	0.0001
Glyphosate rate	3.96091687	0.0001
(Glyphosate rate)^2	-1.64537	0.0001
Julian date	-0.026041	0.0001
Sin[trans(date)]	-2.10798	0.0001
Site Two		
Survival, percentage		
Intercept	97.77547212	0.0001
Glyphosate rate	-49.9261	0.0014
(Glyphosate rate)^2	13.65379184	0.0512
Julian date	-0.0756306	0.1430
Rate x date interaction	0.0940154	0.1028
Height, centimeters		
Intercept	39.50472151	0.0001
Glyphosate rate	-25.8049	0.0001
(Glyphosate rate)^2	11.12361888	0.0072
Julian date	0.0436936	0.0217
Injury rating		
Intercept	4.37169507	0.0002
Glyphosate rate	2.66833521	0.0001
(Glyphosate rate)^2	-1.0527	0.0001
Julian date	-0.0165471	0.0058
Sine[trans(date)]	-1.37879	0.0064

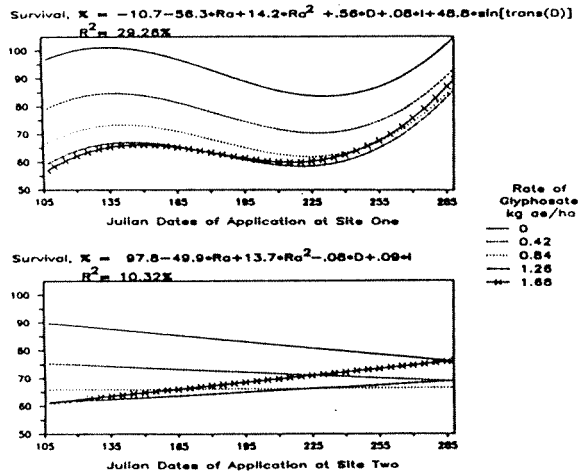

Figure 1. Predicted survival of loblolly pine seedlings from April 15 to October 15 (Julian dates 105 to 288) by rates of glyphosate at site one (top) and site two (bottom). Abbreviations in equations are provided in the text, above.

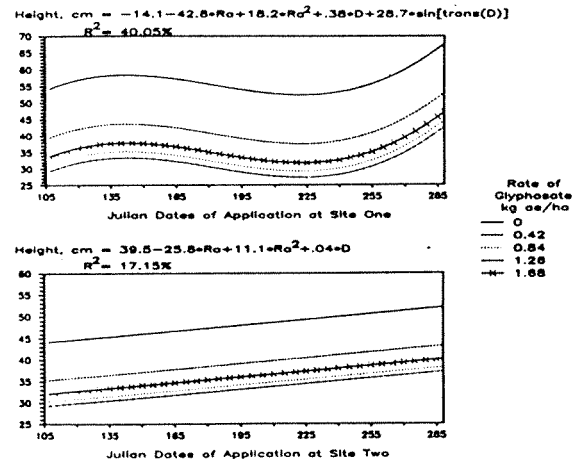

Figure 2. Predicted height of loblolly pine seedlings from April 15 to October 15 (Julian dates 105 to 288) by rates of glyphosate at site one (top) and site two (bottom). Abbreviations in the equations are provided in the text, above.

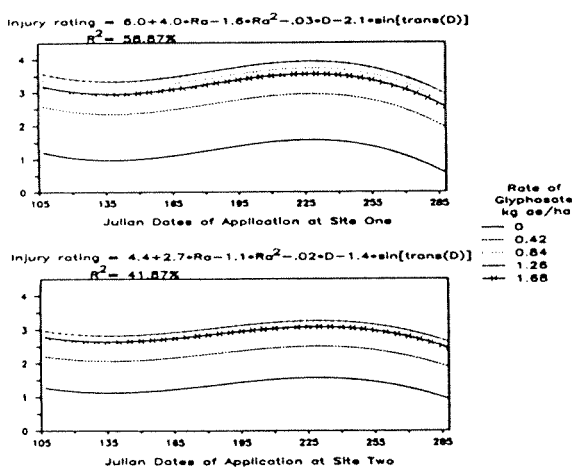

Figure 3. Predicted injury ratings of loblolly pine seedlings from April 15 to October 15 (Julian dates 105 to 288) by rates of glyphosate at site one (top) and site two (bottom). The 0.84 kg ae/ha response curve is hidden by the 1.68 kg ae/ha response curve. Abbreviations in the equations are provided in the text, above.

Conclusions

The combined adverse effects of glyphosate on loblolly pine survival, height, and vigor suggest that this herbicide should not be broadcast over 1st-year seedlings at 0.42 to 1.68 kg ae/ha, even though these rates corresponded to those recommended on the label. However, glyphosate is not labeled for application until conifer seedlings are established for more than 1 year, when rates as high as 0.84 kg ae/ha are used. Therefore our study may have been too severe a test of this herbicide's capabilities.

Glyphosate was a very effective weed control agent, even at the rate of 0.42 kg ae/ha. Perhaps treatments at rates lower than those on the label would not cause unacceptable injury to seedlings but still provide sufficient weed control. Based on the survival and

height data, we concluded that the overall best date of treatment was October 14, although results were less than satisfactory. This conclusion corresponds to the label directions for the rates of 1.26 and 1.68 kg ae/ha for loblolly pine release.

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