Response of Young Pecan Trees to Trunk and Foliar Applications of Glyphosate

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Abstract. A field experiment was conducted from 1995 to 1999 in central Alabama to determine the effect of repeated applications of glyphosate herbicide on young ‘Sumner’ pecan trees. Herbicide treatments were applied on ‘Sumner’ pecan trees varying in age from newly established (first growing season) to established fourth-year growing season trees. Measurements taken included tree mortality, trunk cross-sectional area, nut yield, and nut quality in the third and fourth years of the study. Glyphosate applications were targeted at the lowest 5 to 8 cm of the tree trunk (“standard” treatment), a percentage (lowest 33%, 67%, or 100%) of the tree trunk below the first scaffold limb, or a percentage (lowest 25%, 50%, 75%, or 100%) of tree foliage to simulate situations ranging from minor spray drift to major misapplication. No adverse effects were detected when glyphosate was applied to trunks, regardless of tree age. However, repeated application of glyphosate to 75% to 100% of tree foliage resulted in a significant reduction of growth and, in some cases, tree death. Results indicate that limited contact of glyphosate with the lowest 5 to 8 cm of the trunk of the young pecan tree, which usually occurs during conventional orchard weed management, is unlikely to result in adverse effects on young pecan trees.

Weed competition can reduce growth (Patterson et al., 1990; Smith et al., 2002; Wolf and Smith, 1999), yield (Foshee et al., 1997; Patterson and Goff, 1994), and nut quality (Daniell, 1974) of pecan trees. This reduction in growth has been attributed to competition for nutrients (Bould and Jarrett, 1962; Goff et al., 1991; Worley and Carter, 1972) and water (Patterson and Goff, 1994; Ware and Johnson, 1958).

Benefits from improved weed control are well-documented (McEachern and Storey, 1984; Norton, 1970; Norton and Storey,

1970; Patterson et al., 1990; Patterson and Goff, 1994). Several studies have shown that eliminating all weed competition dramatically increases early growth and yield of young pecan trees (Foshee et al., 1997; Smith et al., 2002, 2005a; Wolf and Smith, 1999). In addition, mulching has been shown to be effective in increasing growth of young pecan trees, although the application of mulch is labor-intensive and costly (Merwin et al., 1994; Smith et al., 2000).

An optimum vegetation-free area has been established by Smith et al. (2005b) to be a circle 1.83 m in diameter around young pecan trees in bermudagrass [*Cynodon dactylon* (L.) Pers.] sod. This resulted in maximum tree growth during the first 5 years of growth. Smith et al. (2002) showed similar results in tall fescue [*Schedonorus phoenix* (Scop.) Holub (syn. *Festuca arundinacea* Schreb.)] sod with maximum tree growth obtained with a vegetation-free circle 0.91

m in diameter around newly planted pecans after only 2 years.

Wolf and Smith (1999) reported that growth of young pecan trees was reduced dramatically when one selected dicotyledonous weed species [cutleaf evening primrose (*Oenothera lacinata* Hill) or Palmer amaranth (*Amaranthus palmeri* S. Wats.)] was allowed to grow near pecan seedlings, possibly as a result of some allelopathic interaction. In a follow-up study, Smith et al. (2001) documented that growth of container-grown pecans was reduced when trees were irrigated with leachate collected from pots of cutleaf evening primrose.

Typical weed control practices in pecan orchards include preemergent and postemergent herbicide applications (Patterson et al., 1990). Either paraquat [1,1'-dimethyl-4,4'-bipyridinium dichloride] or glyphosate [N-(phosphonomethyl)glycine] is used for most postemergent applications (Patterson et al., 1990). Paraquat is a restricted-use pesticide and an Environmental Protection Agency (EPA) Class I pesticide as a result of acute toxicity (Miller, 1996a). Glyphosate, on the other hand, is an EPA Class IV pesticide and is very safe for applicators (Miller, 1996b). Smith et al. (2005a) reported that glyphosate controlled all weed species in a study conducted to determine the effects of temporal weed interference in young pecan trees. Glyphosate has excellent postemergent activity against most dicotyledonous and monocotyledonous weed species. Reynolds et al. (2000) and McClelland and Webster (1998) reported excellent glyphosate activity on cutleaf evening primrose, which is typically not controlled with preemergent herbicides recommended for pecan orchards in the southeastern United States (Wolf and Smith, 1999). Consequently, glyphosate is commonly used in many pecan orchards (Patterson, 1997), and inadvertent herbicide contact with trees through spray drift is a recurring hazard and a concern for growers.

This 4-year study was conducted to evaluate the effects of glyphosate applied to the trunks or foliage of young pecan trees as reflected by mortality, trunk cross-sectional area (as a measure of growth), nut yield, and nut quality (nuts with kernels). Application treatments were selected to simulate situations ranging from minor spray drift to major misapplication.

Materials and Methods

A young [newly planted, first growing season (first GS) and established, fourth-growing season (fourth GS)] orchard of ‘Sumner’ pecan trees (grafted onto seedling rootstock) was used in this study initiated in 1995 at the E.V. Smith Research Center in central Alabama. Soil at this location was a complex of Wickham and Cahaba sandy loams (fine-loamy, siliceous, semiaactive, thermic Typic Hapludults) with a pH of 6.0. Trees were planted on a 6.1 m × 6.1-m spacing. All trees were fertilized based on composite leaf and soil samples taken in July

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Table 1. Response of young [newly planted, first growing season (first GS) and established, fourth growing season (fourth GS)] Summer pecan trees in an orchard in central Alabama to three annual applications of glyphosate from 1995 to 1999.^z

	Mortality at end of yr 3 (%)		TCSA at end of yr 3 (cm ²)		TCSA at end of yr 4 (cm ²)		Nut yield in yr 3 (kg/tree)		Nuts with kernels in yr 3 (%)	
	First GS trees	Fourth GS trees	First GS trees	Fourth GS trees	First GS trees	Fourth GS trees	First GS trees	Fourth GS trees	First GS trees	Fourth GS trees
Targeted tissue:										
None (nontreated)	20	0	16.9	64.2	31.8	81.6	0.51	0.51	50.4	50.4
Lowest 5 to 8 cm of trunk ("standard")	25	0	16.6	71.3	43.0	94.7	0.54	0.54	49.5	49.5
Lowest 33% of trunk	17	0	20.5	73.2	33.6	106.4	0.87	0.87	51.9	51.9
Lowest 67% of trunk	25	0	11.1	76.0	29.3	107.9	0.72	0.72	50.4	50.4
100% of trunk	17	0	12.1	80.6	26.2	114.6	0.44	0.44	48.7	48.7
Lowest 25% of foliage	0	0	16.5	72.9	30.5	98.5	0.83	0.83	50.6	50.6
Lowest 50% of foliage	50	0	9.3	48.7	29.7	69.4	0.16	0.16	47.3	47.3
Lowest 75% of foliage	40	20	6.1	23.5	12.6	37.5	0.09	0.09	51.0	51.0
100% of foliage ^y	100	100								
Significance of overall treatment effects and contrasts ^a :										
Treatment effects	0.0165	<0.0001	0.0913	<0.0001	0.1928	<0.0001	0.0186	0.0186	0.0171	0.0171
Trunk treatments versus foliage treatments ^w	1.0000	1.0000	0.1479	<0.0001	0.2961	<0.0001	0.0322	0.0322	0.3436	0.3436
Trunk treatments (linear)	1.0000	1.0000	0.0481	0.3788	0.3354	0.5211	0.0945	0.0945	0.0062	0.0062
Foliage treatments (linear)	0.0003	<0.0001	0.0340	<0.0001	0.0473	0.0002	0.0047	0.0047	0.8050	0.8050
Nontreated versus lowest 5 to 8 cm of trunk	0.8580	1.0000	0.9512	0.3895	0.2236	0.3057	0.8801	0.8801	0.4375	0.4375
Nontreated versus lowest 33% of trunk	0.8867	1.0000	0.4027	0.2754	0.8249	0.0581	0.1693	0.1693	0.2092	0.2092
Nontreated versus lowest 67% of trunk	0.8580	1.0000	0.2519	0.1589	0.7910	0.0452	0.3540	0.3540	0.9984	0.9984
Nontreated versus 100% of trunk	0.8867	1.0000	0.2765	0.0535	0.4761	0.0134	0.7390	0.7390	0.1411	0.1411
Nontreated versus lowest 25% of foliage	0.1927	1.0000	0.9317	0.2945	0.8677	0.1897	0.1544	0.1544	0.8977	0.8977
Nontreated versus lowest 50% of foliage	0.3406	1.0000	0.1338	0.0681	0.8439	0.3448	0.1000	0.1000	0.0151	0.0151
Nontreated versus lowest 75% of foliage	0.4870	1.0000	0.0367	<0.0001	0.0501	0.0043	0.0839	0.0839	0.7393	0.7393
Nontreated versus 100% of foliage	0.0036	<0.0001								
Lowest 5 to 8 cm of trunk versus lowest 33% of trunk	0.7487	1.0000	0.4009	0.8142	0.3097	0.3627	0.2158	0.2158	0.0369	0.0369
Lowest 5 to 8 cm of trunk versus lowest 67% of trunk	1.0000	1.0000	0.3089	0.5732	0.1766	0.3051	0.4315	0.4315	0.4369	0.4369
Lowest 5 to 8 cm of trunk versus 100% of trunk	0.7487	1.0000	0.3416	0.2669	0.0650	0.1256	0.6289	0.6289	0.4489	0.4489
Lowest 5 to 8 cm of trunk versus lowest 25% of foliage	0.1570	1.0000	0.9868	0.8481	0.1571	0.7672	0.1977	0.1977	0.3406	0.3406
Lowest 5 to 8 cm of trunk versus lowest 50% of foliage	0.4620	1.0000	0.1768	0.0093	0.2454	0.0539	0.0743	0.0743	0.0621	0.0621
Lowest 5 to 8 cm of trunk versus lowest 75% of foliage	0.6327	1.0000	0.0513	<0.0001	0.0057	0.0003	0.0642	0.0642	0.3704	0.3704
Lowest 5 to 8 cm of trunk versus 100% of foliage	<0.0001	<0.0001								

^zGlyphosate applications were targeted at the lowest 5 to 8 cm of the tree trunk ("standard" treatment), a percentage (lowest 33%, 67%, or 100%) of the tree trunk below the first scaffold limb, or a percentage (lowest 25%, 50%, 75%, or 100%) of tree foliage to simulate situations ranging from minor spray drift to major misapplication. One nontreated group (no glyphosate applications; light rotary tillage only for weed control) was also included. Response was evaluated based on whole-tree mortality of both tree ages after 3 years of glyphosate applications, tree growth as measured by trunk cross-sectional area (TCSA) of trees of both ages after 3 and 4 years of glyphosate applications, and nut yield and nut quality (percentage of nuts with kernels) from fourth growing season (GS) trees in year 3. Response values shown are least squares means.

^yTrees killed by applications of glyphosate to 100% of foliage were dead by the time of data collection at the end of year 3 and were therefore excluded from further analyses.

^x*P* values for contrasts are based on χ^2 statistics from generalized linear model analyses (for mortality) and *F* statistics from single-degree-of-freedom contrasts generated in linear model analyses (for TCSA, yield, and percentage of nuts with kernels). *P* values are unadjusted for multiple contrasts. (If an experimentwise significance level of 0.05 with a Bonferroni correction were selected, the significance level for each contrast would be 0.05 $\div$ 18 = 0.0028 for mortality and 0.05 $\div$ 16 = 0.0031 for TCSA, yield, and percentage of nuts with kernels.)

^w"Trunk treatments" refers to the lowest 33%, 67%, and 100% of trunk treatments. "Foliage treatments" refers to the lowest 25%, 50%, 75%, and 100% of foliage treatments for mortality and the lowest 25%, 50%, and 75% of foliage treatments for TCSA, yield, and percentage of nuts with kernels.

of each year (O'Barr et al., 1989). Standard orchard maintenance practices for disease control and cultural considerations were common to all trees throughout the study (Daniell, 1989; Goff, 1989). Weeds on the orchard floor were controlled with a pre-emergent application of recommended herbicides (Patterson, 1997). These included a mixture of oryzalin [3,5-dinitro- N_4,N_4 -dipropylsulfanilamide] applied at a rate of 3.36 kg·ha⁻¹ a.i. and diuron [N'-(3,4-dichlorophenyl)-N,N-dimethylurea] applied at a rate of 3.36 kg·ha⁻¹ a.i. In addition, paraquat (0.56 kg·ha⁻¹ a.i.), a postemergent herbicide, was included in the mixture to kill any remaining winter annual weeds present. Herbicides were applied with a three-nozzle, CO₂-powered sprayer mounted on an all-terrain vehicle and calibrated to deliver 187 L·ha. Rotary tillage (without any herbicide applications) every 4 to 6 weeks to a depth of 7.6 to 10.1 cm with a tractor-mounted, 15-cm wide rotary tiller (model RTS40-01; Bush Hog, Selma, AL) was used to control weeds around trees in one treatment. The orchard was not irrigated. All first GS trees were measured at planting and blocked according to similar size classes to decrease variability. In addition, established fourth GS trees were measured and grouped into blocks according to size.

Treatments were as follows: 1) nontreated (no glyphosate applications; rotary tillage only for weed control); 2) glyphosate applied to the lower 5 to 8 cm of the trunk (representing the "standard" treatment in orchards where limited glyphosate spray drift occurs during conventional orchard weed management); 3–5) glyphosate applied to the lowest 33%, 67%, and 100%, respectively, of the trunk below the lowest scaffold limb (fourth GS trees) or lowest leaf (first GS trees); and 6–9) glyphosate applied to the lowest 25%, 50%, 75%, and 100%, respectively, of the foliage, which was measured and calculated (selected levels were tagged on the trunk of the trees with flagging tape to guide spray applications). Glyphosate treatments were assigned to individual trees using a randomized complete block experimental design with six blocks (replications) for each age of tree. Glyphosate (Roundup Ultra; Monsanto Agricultural Products, St. Louis, MO) was applied at a rate of 1.12 kg·ha⁻¹ a.i. using a backpack CO₂ sprayer calibrated to deliver 140 L·ha⁻¹ of spray volume. Treatments were applied with a backpack sprayer calibrated to deliver 140 L·ha⁻¹. Sprayer was equipped with three 8004E T-Jet (Spraying Systems Co., Wheaton, IL) flat fan nozzles spaced evenly on a 1.4-m wide boom. No adjuvants were added to spray solution (included in formulation); the spray water came from a well with a pH of 6.2. Each tree was sprayed from two sides by an applicator working from the orchard alleys on each side of the tree. Trees were sprayed three times, 60 d apart, starting 15 Apr. of each year during this 4-year study. Tree mortality was determined for trees of both ages at the end of the third year of application. Trunk cross-sectional

area (TCSA) was determined using a measure of trunk circumference at a marked point 15 cm aboveground level as a measure of growth for trees of both ages at the end of years 3 and 4. Pecan nut yield (weight of nuts harvested from each tree) and nut quality (percentage of nuts with kernels) were determined for fourth GS trees at the end of year 3 only as a result of a crop failure in year 4, which was attributed to the off-crop year that is often seen in pecans (Goff, 1989).

Data were analyzed for each age of tree separately using a generalized linear model (binomial distribution and probit link function) with the GENMOD procedure of SAS (version 9.1; SAS Institute, Cary, NC) for mortality and a general linear model with the GLM procedure of SAS for TCSA, nut yield, and percentage of nuts with kernels.

Results and Discussion

Newly planted (first growing season) trees. At the end of year 3, application of glyphosate to 100% of the foliage resulted in greater tree mortality compared with nontreated trees and trees receiving the "standard" treatment (glyphosate applied to the lowest 5 to 8 cm of the trunk) (Table 1). Mortality of trees receiving other glyphosate treatments was similar to untreated trees and trees receiving the "standard" treatment. Tree mortality increased linearly as the amount of foliage receiving application of glyphosate increased from 25% to 100% (Table 1). Because all trees died in response to application of glyphosate to 100% of the foliage, these trees were excluded from further analysis. Data provided no strong evidence (*P* values near or below 0.01) of any adverse effect of glyphosate treatments on TCSA in comparison with nontreated trees at the end of year 3.

At the end of year 4, treatments involving application of glyphosate (12 total applications) to tree trunks had not negatively impacted tree survival or TCSA (Table 1). Data indicated that repeated application of glyphosate to 75% to 100% of the foliage was needed to negatively impact survival or TCSA of these first GS trees. This demonstrates that an occasional "drift application" of glyphosate to the lower trunk of first GS pecan trees in a production orchard is unlikely to have an adverse effect on tree survival or growth.

Foliage sprayed with glyphosate dropped from the trees within 4 to 6 weeks. When trees receiving glyphosate applications to the foliage were not killed, new growth developed abnormally (Fig. 1).

Established (fourth growing season) trees. Effects of treatments on tree mortality of established trees at the end of year 3 were consistent with effects on newly planted, first GS trees. Application of glyphosate to 100% of the foliage resulted in 100% mortality (Table 1); therefore, these trees were excluded from further analysis.

At the end of year 3, trees exhibited an increase in mortality and decrease in TCSA

Fig. 1. Abnormal development of new growth on young 'Sumner' pecan trees (newly planted, first growing season trees at the initiation of the study) after 12 repeated foliar applications of glyphosate (i.e., major misapplication) over 4 years (three applications every 60 d during each growing season) with glyphosate applied at a rate of 1.12 kg·ha⁻¹ a.i.

as the percentage of the foliage receiving applications of glyphosate increased from 25% to 100% (Table 1). Comparison between the trunk and foliage treatments indicated a highly significant difference in TCSA with the trunk treatments group having greater TCSA than the foliage treatments group (Table 1). Nontreated trees exhibited greater TCSA than trees receiving application of glyphosate to the lowest 75% of the foliage (Table 1). In addition, trees receiving the "standard" treatment had greater TCSA than trees that received glyphosate to the lowest 50% and 75% of the foliage (Table 1).

At the end of year 4, some differences in growth among treatments were again evident. Trees receiving application of glyphosate to their trunks had greater TCSAs (≈60% greater) than the foliar-treated trees (Table 1). A decreasing linear response in TCSA with increasing percentage of the foliage receiving glyphosate applications continued to be evident (Table 1). Nontreated trees and trees receiving the "standard" treatment exhibited greater TCSAs than trees receiving glyphosate applications to the lowest 75% of the foliage. Like with first GS trees, foliage receiving applications of glyphosate dropped from the trees within 4 to 6 weeks, whereas any new growth on these trees developed abnormally (Fig. 2).

There was a marginal indication (*P* values ≈0.10) that yield of nuts in year 3 was affected by foliar applications of glyphosate in comparison with results from nontreated trees with yield declining as percentage of the foliage receiving applications of glyphosate increased

Fig. 2. Abnormal development of new growth on young 'Sumner' pecan trees (established, fourth growing season trees at the initiation of the study) after 12 repeated foliar applications of glyphosate (i.e., major misapplication) over 4 years (three applications every 60 d during each growing season) with glyphosate applied at a rate of 1.12 kg·ha⁻¹ a.i.

(Table 1). There was no evidence of any effect on nut quality after 3 years of application. Some indication of a decreasing linear trend in nut quality in year 3 with increasing percentage of the trunk receiving applications of glyphosate (Table 1) was not well substantiated by comparison of trees receiving trunk treatments with nontreated trees or with trees receiving the "standard" treatment.

Results from this 4-year study revealed that application of glyphosate to the trunk of established, fourth GS pecan trees did not significantly affect mortality, growth, yield, or nut quality. However, repeated application of glyphosate to foliage can have an adverse effect. However, occasional drift of glyphosate to the lower trunk of young, established pecan trees is unlikely to cause any adverse effect.

A comparison between nontreated trees and trees receiving applications of glyphosate to the trunk gave some marginal indication that rotary tillage may have negatively affected growth of fourth GS trees, possibly by the disk itself damaging feeder roots, but this was not clearly established. Tillage in pecan orchards is not recommended as a result of reduction in yields from moisture loss (Patterson and Goff, 1994) and damage to feeder roots (Goff, 1989).

Effects of glyphosate contact with young pecan trees have not been previously reported. The use of glyphosate in pecan orchards would be beneficial to pecan growers, particularly to clean up troublesome weeds like cutleaf evening primrose, which at very low number has been shown by Wolf and Smith (1999) to dramatically

reduce growth of young pecan trees. Results of this study indicate that occasional contact of young pecan trees with glyphosate is unlikely to significantly affect tree growth or survival.

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