PERFORMANCE EVALUATION OF SEEDLING PECAN TREES USING COMMONLY SELECTED AND COMMERCIALLY AVAILABLE TREE SHELTERS AND THE EFFECT OF GLYPHOSATE APPLICATION ON PECAN KERNEL NECROSIS

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CHAPTER I

INTRODUCTION

As a naturally occurring plant in the Mississippi Valley, pecan [*Carya illinoinensis* (Wangenh.) K. Koch] is the only major tree nut native to the United States (Cochran, 1961). With the recent increase in demand for pecans, especially within the international market, there has been a dramatic increase in the establishment of new orchards (C. Rohla, personal communication). During establishment of pecan trees, vegetation control is a critical management practice for maximizing growth and increasing tree survival. Studies have shown that weed competition can dramatically reduce growth (Foshee et al., 1995; Griffin et al., 2007; Patterson and Goff, 1994; Smith et al., 1959; Smith et al., 2002), nut quality (Daniell, 1974) and yield (Foshee et al., 1997; Hunter, 1950; Patterson et al., 1990; Patterson and Goff, 1994) of pecan trees. Several species of monocot and dicot plants have negative allelopathic effects (Friedman and Horowitz, 1970; Meissner et al., 1989; Menges, 1987; Patterson et al., 1990; Smith et al., 2002; Wolf and Smith, 1999) reducing performance of young trees. Competition for water (Blackmon, 1948; Hardy, 1939; Patterson and Goff, 1994; Ware and Johnson, 1958) and nutrients (Blackmon, 1948; Bould and Jarrett, 1962; Goff et al., 1991; Hardy, 1939; Worley and Carter, 1972) from competing vegetation has been implicated in reducing tree growth.

Smith et al. (2005) showed that a vegetation-free area of 1.83-meters in diameter was optimal for maximum growth of young pecan trees grown in bermudagrass [*Cynodon dactylon (L.) Pers.*] sod. Young pecan trees grown in tall fescue [*Schedonorus phoenix (Scop.)* Holub (syn. *Festuca arundinacea* Schreb.)] sod, had maximum growth with a vegetation-free area of 0.91-meters (Smith et al., 2002).

Herbicides are commonly used to control grasses and weeds around trees (Aitken, 1974; Arnold and Aldrich, 1979; Foshee et al., 1997; Foshee et al., 2008; Merwin and Ray, 1997; Merwin and Stilies, 1994; Merwin et al., 1994; Norton and Storey, 1970; Patterson and Goff, 1994). Glyphosate (N-phosphonomethylglycine), a broadspectrum non-selective herbicide, is commonly used for control of vegetation in pecan orchards (Patterson et al., 1990; Patterson, 1997). According to the label for glyphosate, extreme caution should be used when applying glyphosate around young trees to avoid contact with foliage and green bark of trunks and branches. Foshee et al. (2008) showed there was little to no damage on young pecan seedlings when glyphosate was applied to the lower trunk area. However, growers maintaining a vegetation free area around young trees often use physical barriers to protect trees from contact. Common practices include wrapping the trunk with aluminum foil, using shields during applications, or utilization of tree protectors/shelters around the lower trunks of young trees. There is a concern that the use of tree protectors/shelters will cause an increase in the temperature and humidity around the tree leading to trunk damage, disease problems, or tree death.

Tree protectors/shelters are utilized to protect trees by eliminating herbicide contact to the trunk, thus reducing the chance of damage. Tree protectors/shelters are used in many woody species and vineyard establishments to increase growth of the plants

(Burger et al., 1992; Frearson & Weiss, 1987; West et al., 1999; Hart, 1991; Potter, 1988, 1991). These protectors/shelters form a micro-climate around the plant and encourage faster growth. Tree protectors/shelters are also used to protect newly established plants from wildlife browse.

During the past ten years the cultivar ‘Pawnee’ has been the primary cultivar of pecans planted in Oklahoma and northern Texas (Smith et al., 2007). This popularity is directly correlated to the ability of the ‘Pawnee’ to produce early, high quality, large pecans. One problem that has been identified with ‘Pawnee’ growing in the Red River Basin of Oklahoma and Texas is kernel necrosis. Characterized by necrotic tissue located on the basal end of the kernel, the cause of kernel necrosis is unknown. Kernel necrosis was first detected by a grower in north-central Texas. Further investigation resulted in finding kernel necrosis on the cultivars ‘Pawnee’, ‘Choctaw’ and ‘Oklahoma’ (Smith et al., 2007). Damage from kernel necrosis has been as high as 25% in some affected orchards (M.W. Smith, personal communication).

High-input pecan orchards seem to be more likely to experience kernel necrosis. The normal management of the orchard includes multiple applications of glyphosate to control vegetation around pecan trees. Observations of orchards with kernel necrosis have led to the development of a working hypothesis that glyphosate drift may cause or enhance the occurrence of the disorder. Glyphosate is a foliar-applied, broad- spectrum, non-selective, herbicide that is applied postemergent to vegetation, and is toxic to most plants and many bacteria (Steinrucken et al., 1986; Steinrucken & Amrhein, 1980). Glyphosate is the most widely used herbicide to control vegetation surrounding pecan trees. Charles Reilly, United States Department of Agriculture-Agricultural Research

Service, analyzed 'Pawnee' liquid endosperm from an orchard in Charlie, Texas where kernel necrosis had been found and from an additional orchard near Stillwater where kernel necrosis was not found. He indicated that the concentrations of amino acids and ureides were similar, but certain phenolic compounds were elevated (unpublished data). This suggests the shikimic acid pathway may be affected. The mode of action for glyphosate is to inhibit this pathway (Franz et al., 1997). The shikimic acid pathway is used to synthesize essential aromatics that are important for protein synthesis (Hatcher and Kruger, 1997). All growers reporting kernel necrosis have orchards under an intensive management regime and rely primarily on glyphosate for vegetation control. Drift onto leaves and fruit, or absorption through the trunk or root system could lead to death of the most sensitive active tissue; in this case the developing cotyledon. Glyphosate in soil has been reported to have a long half-life ranging from weeks to several years (Feng and Thompson, 1990; Nomura and Hilton, 1977; Roy et al., 1989). Coupland and Casely (1979) demonstrated that glyphosate accumulated in roots of plants and released into the rhizosphere. There is also some evidence that glyphosate may affect absorption of Fe, Zn, Mn (Franzen et al., 2003; Jolley et al., 2004; Romheld et al., 2005) and Ni (Bai et al., 2006).

Glyphosate was evaluated as the cause of kernel necrosis because the damage to the pecan kernels has increased phenolic compounds, which suggests that the shikimic acid pathway is being affected. There has been several research studies indicating glyphosate effects on growth rate, yield (Zablotowicz & Reddy, 2004) and nutrient uptake (Bai et al., 2006; Eker et al., 2006; Gordon, 2007; Johal and Huber, 2009; Jolley et al., 2004; Kremer et al., 2005; Neumann et al., 2006; Tesfamariam et al., 2009) in other crops such as soybeans, and sunflowers.

Objectives

The objectives of these studies were to: 1) evaluate the growth and overall health of seedling pecan trees that were grown in a variety of commonly used physical barriers and commercially available tree protectors/shelters; 2) determine if the use of glyphosate around pecan trees increases the occurrence of kernel necrosis in ‘Pawnee’ pecans; 3) determine if glyphosate drift onto the leaves and/or fruit of ‘Pawnee’ pecans increases the occurrence of kernel necrosis.

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CHAPTER II

PERFORMANCE EVALUATION OF SEEDLING PECAN TREES USING COMMON PHYSICAL BARRIERS AND COMMERCIAL TREE SHELTERS

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ABSTRACT.

Sixty-eight 'Peruque' seedlings were planted in 2008. Thirteen tree shelters and two physical barriers typically used by pecan growers were assigned at planting to each tree. Non-sheltered trees served as the negative control for the study. Protex Pro/Gro solid tube tree protectors had a 65% larger diameter than trees grown in Clipper shelters. The first year's total shoot growth of trees grown using Snap n

Grow tubes and Protex Pro/Gro solid tube tree protectors was 54% larger than Blue X shelters. Total shoot growth of trees grown using Protex Pro/Gro solid tube tree protectors was 64% larger than trees grown using Wholesale Ag shelters. Trees subjected to all treatments, including the control, had sunken cankers on the trunk. However, the damaged areas of the trunks did not influence the overall growth of the pecan trees. Any negative aesthetic issue caused by the presence of the canker was short lived, because the damage could not be observed once the bark matured.

Keywords: *Carya illinoinensis,*

Weed control is a critical management practice for maximizing growth and survival of newly established pecan trees (*Carya illinoinensis* (Wangenh.) K Koch). Several studies have demonstrated that grass and weed competition can dramatically reduce growth of immature pecan trees. Species of monocot and dicot vegetation can have allelopathic effects on young pecan trees (Patterson et al., 1990; Smith et al., 2002; Wolf and Smith, 1999). Competition for water (Patterson and Goff, 1994; Ware and Johnson, 1958) and nutrients (Bould and Jarrett, 1962; Goff et al., 1991; Smith et al., 1959; Worley and Carter, 1972) by weeds has been implicated in reducing pecan tree growth. In several studies, controlling vegetation around pecan trees increased tree growth during establishment (Foshee et al., 1995; Patterson et al., 1990; Patterson and Goff, 1994; Smith et al., 2002; Wolf and Smith, 1999). In order for producers to achieve optimal pecan production, controlling vegetation is critical. The combination of allelopathy and competition for available resources is typically referred to as interference.

To limit interference, herbicides are typically used to control weeds surrounding young pecan trees (Foshee et al., 1997; Merwin and Stiles, 1994; Merwin et al., 1994; Norton and Storey, 1970; Patterson et al., 1990; Patterson and Goff, 1994). However, damage to trees can result from certain herbicides if direct contact occurs (Foshee et al., 2008). Tree shelters (cylinders constructed of various materials that surround and protect the trunk) can be utilized to protect trees by eliminating contact with the trunk thus reducing the chance of herbicide damage. Tree shelters are used during establishment for many woody plant species to increase growth of the plants (Burger et al., 1992; Frearson & Weiss, 1987; West et al., 1999; Hart, 1991; Potter, 1988, 1991). These shelters form a micro-climate around the plant and encourage faster growth. Tree shelters are also used to protect newly established plants from wildlife browse. However, there is limited research regarding the effects of tree shelters on performance of pecan trees.

In pecan establishment, tree shelters are used to protect young pecan trees for three main purposes: 1) to protect the trunks from winter cold injury frequently referred to as sunscald, 2) to protect trees from contact with herbicides that might result in damage and 3) to protect trees from wildlife feeding on tender bark. In other woody species research has indicated that tree shelters have significantly influenced the growth of trees. Cherry (*Prunus avium* L.) seedlings grown with tree shelters were 60% taller than seedlings without shelters after three seasons and oak (*Quercus spp*. L.) seedlings grown with tree shelters were 600% taller than those without shelters after three years (Frearson and Weiss, 1987; Potter, 1988). Other benefits attributed to tree shelters are increased temperatures around the seedling inside the shelter and improved soil moisture levels. Increased soil moisture found within tree shelters is caused by condensation that enters the soil, which is a result of super-saturation from high relative humidity (Potter, 1988; Ponder, 1995). Ponder (1995) also observed an increase in nutrient uptake using tree shelters during establishment.

With the increased temperature and relative humidity inside tree shelters some pecan growers have expressed concern that damage or death may occur when using tree shelters. Some proponents of tree shelters acknowledge this increased temperature as a growth benefit for young trees; however, no research has been conducted on pecan concerning this theory.

OBJECTIVES

(1) Characterize temperature and relative humidity near the trunk of young pecan trees contained by various types of tree shelters in a newly established orchard.
(2) To determine the effect of various types of tree shelters on the growth of young pecan trees in a newly established orchard.

(3) To monitor tree health and identify the cause of damage that might develop as a result of being contained in various types of tree shelters and determine the causal agent.

MATERIALS AND METHODS

Sixty-eight, three year old ‘Peruque’ seedlings (19.24 mm in diameter at 76 cm, standard deviation 2.51) were planted at The Samuel Roberts Noble Foundation’s McMillan research farm in Marshall County, Oklahoma, in the winter of 2008. All trees were pruned to the height of 90-centimeters at planting. Weeds were controlled with glyphosate applied five times per year to maintain a 1.8-meter wide vegetation-free strip centered on the tree row. The control treatment was shielded during herbicide application to eliminate potential herbicide contact and resulting damage. All trees were irrigated with a solid set sprinkler system and fertilized by applying 0.5 kg/tree of 19N-8.17P-15.77K the first year, and then 0.5 kg/tree of 46N-0P-0K the second year. Fertilizer was applied during the last week of March in both years. Trees were planted on a Bastrop fine sandy loam soil (fine-loamy, mixed, active, thermic, udic Paleustalfs).

Thirteen tree shelters typically used by pecan growers were included in the study along with white latex paint (50% latex paint: 50% water) sprayed directly on the trunk and aluminum foil wrapped around the trunk (Table 1). Each shelter represented a treatment and each treatment was replicated four times using single-tree plots in a randomized complete block design. Eight trees that were not sheltered or painted served as the negative control for the study.

Ambient temperature and relative humidity were recorded using WatchDog B-Series Button Loggers from Spectrum Technologies, Inc, (Plainfield, IL). During August in both growing seasons, a logger was placed next to the trees on the south side, 15-centimeters above the ground on three trees per treatment for a total of 45 trees sampled. The data loggers were programmed to sample temperature and relative humidity every 30 minutes. Highest and lowest temperature and relative humidity was recorded for the entire month of August.

Total current season shoot growth and trunk diameter 76-centimeters above the ground were measured annually during dormancy for both seasons of the trial. Trunks were also evaluated for damage and dead tissue on the lower 60-centimeters of the trunk (Figures 1 & 2). Incidence, severity, and location of damaged trunk tissue were also determined for all plots.

Data was analyzed in SAS 9.2 utilizing a mixed model for analysis of variance. Comparisons of treatment means were performed using the protected least significant difference (LSD) test ($P<0.05$).

Results and Discussion

During the first year, fourteen of the sixty-eight trees died (Table 2). Trees were replaced in the spring of 2009 and nine trees died during the 2009 growing season (Table 2). Three of the four trees grown using the black drain pipe died in 2009 and two of the replacement trees died in 2010; therefore growth data from trees protected with the black drain pipe was omitted from the study, but disease incidence and severity was collected from the surviving trees. Dead trees were replaced each year and temperature and relative humidity data was collected and analyzed on all treatments.

Trunk diameter increase over the two growing seasons for all treatments was not significantly different from the control (Table 3). Trunks of trees sheltered with Clipper were smaller than those using TP tube vented and Protex. Otherwise, treatments resulted in similar trunk diameter growth. No treatment produced significantly more total current season growth during the first year (2009) than the control (Table 3). Trees protected with Protex had more shoot growth in 2009 than those sheltered by Tubex, Blue X, TP tube unvented and TP Protectors vented, but tree growth using these shelters was similar to the other treatments included in this study. Total current season shoot growth the second year (2010) was higher in trees grown using the Snap n Grow and the Protex than the control trees grown without any protection, with the Corrugated and Ag shelters (Table 3). Total shoot growth for the two years was significantly greater than the control for trees grown using Protex and Snap n Grow tree shelters (Table 3).

The average temperature during August was significantly higher inside the Blue X, Tubex, TP protectors vented and unvented than the temperature around the control trees grown without any protection (Table 4). The average relative humidity of all treatments was similar to the control. The average relative humidity was higher in the Ag shelters than the ambient humidity when trees were painted with white latex (Table 4). The maximum temperature of trees grown inside the Corrugated shelters was lower than that of the control trees grown without any protection (Table 4). The maximum temperature during August was higher inside the TP Protectors unvented than paint, foil, Ag shelter, Cardboard container and the Corrugated. There was no significant difference between low temperature readings for all treatments. The control had a higher maximum relative humidity than the Ag shelter, the Corrugated, the TP Protectors unvented and the foil (Table 4). There were no significant differences of low relative humidity readings for all treatments (Table 4).

Tissue damage was found on the seedling pecan trees; however, it was not exclusively associated with shelters as damaged tissue was also found on the control trees (Table 5). The damaged tissue was found on all sides of the trees. Location and percentage of trunk damaged was not significant across all trees in the study. The pathogen associated with damaged tissue was isolated by the Oklahoma State University Plant Disease and Insect Diagnostic lab as a *Botryosphaeria* sp., but Koch's postulates were not completed. This fungus is suspected in contributing to the damage observed, but it appears that the damage does not affect the growth of the trees. Once the bark on the trunks starts to turn rough, the damaged areas cannot be found.

Conclusion

Competition for water and nutrients by vegetation can impact tree performance. Controlling vegetation around pecan trees has been proven to increase tree growth during establishment (Foshee et al., 1995; Patterson et al., 1990; Patterson and Goff, 1994; Smith et al., 2002; Wolf and Smith, 1999). In order for producers to achieve optimal pecan production, controlling vegetation is critical. The combination of allelopathy and competition for available resources is typically referred to as interference. To limit this interference, herbicides are typically used to control vegetation surrounding young pecan trees (Foshee et al., 1997; Merwin and Stiles, 1994; Merwin et al., 1994; Norton and Storey, 1970; Patterson et al., 1990; Patterson and Goff, 1994). However, damage to trees can result from certain herbicides if direct contact occurs during spraying (Foshee et al., 2008). Tree shelters can be utilized to protect trees by eliminating contact with the trunk thus reducing the chance of herbicide damage. Tree shelters are used during establishment for many woody tree species and vineyards to increase growth of the plants (Burger et al., 1992; Frearson & Weiss, 1987; West et al., 1999; Hart, 1991; Potter, 1988, 1991). These shelters form a micro-climate around the plant and encourage faster growth. The results from this study suggest that tree shelters can be used to protect newly established plants from herbicide contact. Some shelters caused an increase in temperature and relative humidity inside the shelters, while others reduced temperature and relative humidity. Tubex, Blue X and TP protectors had a higher average temperature than the control. Corrugated shelters had a lower high temperature than the control treatment. TP tube unvented and the Protex shelters increased the diameter of seedling pecan trees over the control. Protex Pro/Gro solid tube tree protectors had 65% larger diameter than trees grown in Clipper shelters. While the Protex and Snap n Grow increased the total growth of the seedlings over the control. The first year's total shoot growth of trees grown using Snap n Grow tubes and Protex Pro/Gro solid tube tree protectors were 54% larger than Blue X shelters. Total shoot growth of trees grown using Protex Pro/Gro solid tube tree protectors were 64% larger than trees grown using Wholesale Ag shelters. Damaged tissue (caused by *Botryosphaeria sp.)* was observed on all treatments including the control and did not affect the growth of the seedlings. Trees grown with the black drain pipe had the highest severity of damage, while the Tubex, Corrugated and Protex protectors had the lowest severity of damage. The trees seemed to outgrow the damage. As the bark starts to turn rough on the trunks the damaged tissue cannot be seen.

This study indicated that the use of the Protex protectors resulted in the greatest increase in diameter change, cumulative shoot growth and lowest damage severity compared to not using protection around the trunk of the trees during establishment.

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Figure 1. Close up photo showing damage caused by *Botryosphaeria* sp. on young pecan (*Carya illinoinensis*) seedling. Notice the blister appearance above the bud.

Figure 2. Photo of damaged tissue on the trunk of a young pecan (*Carya illinoinensis*) seedling. Notice the green tissue above and below the damaged area and dead tissue (brown) at the site of the damage caused by *Botryosphaeria* sp.

Table 1. Tree shelters and barriers with their manufacturer, level of light transmittance, color, venting capability, and height.

Treatment	Abbreviation	Manufacturer	Light transmittance	color	vented	height (cm)
Control	Control					
Aluminum Foil	Foil		opaque	silver	No	60
White Latex Paint (50-50)	Paint		opaque	white		60
Black Drain Pipe	Pipe		opaque	black	No	76
Tubex Tree Shelters	Tubex	Fiberweb Geosynthetics Ltd. South Wales, UK	translucent	green	No	60
Blue X Tree Shelters	Blue X	Blue-X Enterprises, Inc. Sacramento, CA	translucent	blue	No	76
Clipper Grow Tube	Clipper	Treessentials Company Saint Paul, MN	translucent	tan	Yes	76
Snap n Grow Grow Tube	Snap n Grow	Treessentials Company Saint Paul, MN	translucent	tan	Yes	76
Treepro Miracle Tube Tree Shelters Vented	TP tube vent	Tree Pro West Lafayette, IN	translucent	clear	Yes	76
Treepro Miracle Tube Tree Shelters Unvented	TP tube unvent	Tree Pro West Lafayette, IN	translucent	clear	No	76
Wholesale Ag Tree Shelters	Ag shelter	Farm Wholesale Ag Salem, OR	opaque	white	Yes	76
Corrugated Tree Guards	Corrugated	A.M. Leonard, Inc. Tipp City, OH	opaque	white	No	76
Cardboard Containers	Cardboard	Pacific Western Santa Ana, CA	opaque	white	No	60
TreePro Protectors Vented	TP protectors vented	Tree Pro West Lafayette, IN	translucent	tan	Yes	76
TreePro Protectors Unvented	TP protectors unvented	Tree Pro West Lafayette, IN	translucent	tan	No	76
Protex Pro/Gro Solid Tube Tree Protectors	Protex	Forestry Suppliers, Inc. Jackson, MS	translucent	blue	Yes	60

Table 2. Percent pecan (*Carya illinoinensis*) tree survival per treatment per year.

Treatment	Percent Tree Survival [z] 2009	2010
Control	75	75
Foil	50	100
Paint	75	75
Pipe	25	50
Tubex	100	100
Blue X	100	100
Clipper	75	75
Snap n Grow	75	100
TP tube vent	75	75
TP tube unvented	75	100
Ag shelter	75	75
Corrugated	100	100
Cardboard	100	100
TP protectors vented	75	75
TP protectors unvented	100	100
Protex	100	100

[z] All treatments started with 4 replications and the control started with 8 replications. All dead trees were replaced during both years.

Table 3. Total trunk diameter increase and total shoot growth after two years and total shoot growth per year.

Treatment	Trunk diameter increase (mm)		Total shoot growth 2009 (cm)		Total shoot growth 2010 (cm)		Cumulative shoot growth (cm)	
Control	8.4	ab[z]	11.22	ab[z]	92.87	cd[z]	104.08	cd[z]
Foil	8.25	ab	11.3	ab	130.25	abc	141.55	abc
Paint	7.15	ab	10.63	ab	143.9	abc	154.53	abc
Tubex	6.298	ab	7.85	b	116.33	abcd	124.18	abcd
Blue X	6.96	ab	6.625	b	121.93	abc	128.55	abcd
Clipper	3.68	b	7.93	b	104.87	bcd	112.8	bcd
Snap n Grow	7.41	ab	8.43	ab	168.37	a	176.8	ab
TP tube vented	10.56	a	9.8	ab	128.5	abc	138.3	abc
TP tube unvented	5.98	ab	7.33	b	119.53	abc	126.87	abcd
Ag shelter	4.32	ab	10.8	ab	53.43	d	64.23	d
Corrugated	5.03	ab	10.63	ab	95.53	cd	106.15	cd
Cardboard	5.41	ab	9.28	ab	119.85	abc	129.13	abc
TP protectors vented	5.78	ab	7.47	b	119.57	abc	127.03	abcd
TP protectors unvented	8.63	ab	10.35	ab	105.5	abcd	115.85	abcd
Protex	10.47	a	14.25	a	164.1	ab	178.35	a

[z] Means within column followed by same letter are not significantly different according to the protected $LSD_{0.05}$.

Table 4. Temperature and relative humidity inside the shelters around the pecan (*Carya illinoinensis*) trees.

Treatment	Average Temperature (°C)		Average Relative Humidity (%)		High Temperature (°C)		Low Temperature (°C)		High Relative Humidity (%)		Low Relative Humidity (%)	
Control	22.80	cde[z]	76.90	ab[z]	41.44	abc[z]	5.61	a	109.20	a[z]	22.37	a
Foil	22.51	de	72.41	ab	39.65	cd	6.31	a	103.37	d	17.67	a
Paint	22.59	cde	75.62	b	41.02	bc	5.68	a	107.47	abc	23.10	a
Pipe	22.89	bcde	74.85	ab	42.48	abc	6.15	a	106.47	abcd	18.23	a
Tubex	24.29	a	78.56	ab	45.15	ab	5.98	a	107.17	abcd	27.90	a
Blue X	24.51	a	73.86	ab	44.28	ab	6.15	a	109.03	ab	22.50	a
Clipper	23.74	abc	74.11	ab	43.31	abc	5.78	a	105.97	abcd	21.13	a
Snap n Grow	23.57	abcd	76.59	ab	42.68	abc	6.02	a	106.47	abcd	23.37	a
TP tube vented	23.46	abcd	77.22	ab	41.52	abc	5.81	a	107.47	abc	25.87	a
TP tube unvented	23.62	abcd	79.55	a	43.86	abc	6.36	a	108.00	abc	28.50	a
Ag shelter	22.65	cde	75.52	ab	39.61	cd	5.90	a	105.30	bcd	20.70	a
Corrugated	21.72	e	75.44	ab	36.52	d	6.15	a	104.40	cd	24.93	a
Cardboard	22.18	e	78.17	ab	39.48	cd	5.78	a	105.80	abcd	26.60	a
TP protectors vented	24.05	ab	75.33	ab	45.11	ab	6.11	a	107.10	abcd	23.30	a
TP protectors unvented	24.02	ab	75.90	ab	45.48	a	6.02	a	104.20	cd	23.83	a
Protex	23.40	abcd	77.56	ab	42.78	abc	6.44	a	108.57	ab	25.67	a

[z] Means within column followed by same letter are not significantly different by protected $LSD_{0.05}$.

Table 5. Incidence, occurrence, severity and location of damage on pecan (*Carya illinoinensis)* tree trunks.

	Trees observed for damage	Trees with damage		Occurrence of damage per treatment		Severity of trunk damage		Location of damage
Control	6	4	ab[z]	6	a[z]	35.0	bcde[z]	E, E, W, W, SW, NW
Foil	4	1	ab	2	a	26.0	cdef	W, W
Paint	3	1	b	1	a	23.0	def	SE
Pipe	1	1	ab	1	a	99.0	a	All sides
Tubex	4	2	ab	4	a	17.0	f	NE, E, E, W
Blue X	4	4	a	6	a	28.3	cdef	SE, E, E, N, E, E
Clipper	3	3	ab	5	a	35.8	bcde	S, W, S, SE, S
Snap n Grow	4	3	ab	5	a	38.8	bcd	W, S, E, W, E
TP tube vent	3	2	ab	2	a	53.0	b	S, S
TP tube unvent	4	4	a	7	a	42.0	bc	E, SE, N, NW, S, SE, SE
Ag shelter	3	1	b	1	a	20.0	ef	E
Corrugated	4	2	ab	2	a	18.0	f	NW, S
Cardboard	4	2	ab	3	a	19.3	ef	E, W, SW
TP protectors vented	3	3	ab	4	a	31.5	cdef	E, N, E, N, SW
TP protectors unvented	4	2	ab	3	a	30.0	cdef	NE, W, S
Protex	4	2	ab	5	a	18.0	f	SE, SE, N, NW, W

[z] Means within column followed by same letter are not significantly different by protected $LSD_{0.05}$.

CHAPTER III

THE EFFECT OF GLYPHOSATE APPLICATION ON PECAN KERNEL NECROSIS

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ABSTRACT.

Pecan kernel necrosis is a malady that affects the kernel of pecans. The cause of kernel necrosis is unknown. Glyphosate has been used to control grass and weeds around the trees where kernel necrosis has been identified. Glyphosate drift and uptake by the roots and trunk tissue was evaluated to determine if it was the cause of kernel necrosis. Application of glyphosate to the soil around pecan trees increased the occurrence of kernel necrosis by 89% compared to using paraquat. Severe kernel necrosis was 65% higher on trees treated with glyphosate to the soil compared to trees treated with only paraquat.

Keywords: *Carya illinoinensis,*

Pecan kernel necrosis is a malady that affects the kernel (cotyledon) of the pecan (Smith et al., 2007). Specifically, the basal end of the kernel can develop a darkened area on the testa of the dorsal side that may progress to include the entire basal end of the kernel. The necrotic spots vary in size from barely visible to the majority of the kernel being affected (Smith et al., 2007). The affected area of the kernel will appear black with necrotic tissue (Figure 3). No symptoms have been observed on the shuck when kernels are necrotic. Necrosis has been prominent in ‘Pawnee’, ‘Choctaw’ and ‘Oklahoma’ and rare or non-existent on other cultivars (Figure 4). ‘Pawnee’ and ‘Choctaw” have a common parent ‘Success’, suggesting the problem may be genetically linked. In a research trial were kernel necrosis was evaluated, certain essential elements were found to vary among normal and affected kernels, but these appeared within acceptable ranges (Smith et al., 2007). Some affected orchards have exhibited as high as 25% of the crop with kernel necrosis (M. W. Smith, personal communication, August, 2010). These orchards utilize glyphosate to control vegetation around the trees. It is hypothesized that glyphosate drift, absorption through the bark or interaction with certain plant nutrients may be affecting the incidence of kernel necrosis.

Glyphosate is a foliar-applied, broad-spectrum, non-selective, postemergent herbicide that is toxic to most plants and many bacteria (Steinrucken & Amrhein, 1980; Steinrucken et al., 1986). Glyphosate is the most widely used herbicide to control vegetation surrounding pecan trees. Charles Reilly, United States Department of Agriculture-Agricultural Research Service, analyzed ‘Pawnee’ liquid endosperm from an orchard in Charlie, Texas with a history of kernel necrosis and from an orchard near

Stillwater, Oklahoma with no kernel necrosis detected. Reilly found that the concentrations of amino acids and ureides were similar, but certain phenolic compounds were elevated (unpublished data). This suggests the shikimic acid pathway may be affected. The mode of action of glyphosate is to inhibit this pathway (Franz et al., 1997). Essential aromatics are synthesized in the shikimic acid pathway, which are important for protein synthesis (Hatcher and Kruger, 1997). All growers reporting kernel necrosis have orchards under an intensive management regime that rely primarily on glyphosate for vegetation control. Drift onto leaves and fruit, or absorption through the trunk or root system could lead to death of the most sensitive active tissue; in this case the developing cotyledon. Glyphosate in soil has been reported to have a long half-life ranging from weeks to several years (Feng and Thompson, 1990; Nomura and Hilton, 1977; Roy et al., 1989). Coupland and Casely (1979) demonstrated that translocation of glyphosate within plants, was accumulated in roots and released into the rhizosphere.   There is also some evidence that glyphosate may affect absorption of Fe, Zn, Mn (Franzen et al., 2003; Jolley et al., 2004; Romheld et al., 2005) and Ni (Bai et al., 2006). Glyphosate was evaluated in this study because there have been several research studies indicating glyphosate effects growth rate, yield (Zablotowicz & Reddy, 2003) and nutrient uptake (Bai et al., 2006; Eker et al., 2006; Gordon, 2007; Johal and Huber, 2009; Jolley et al., 2004; Kremer et al., 2005; Neumann et al., 2006; Tesfamariam et al., 2009) on other crops such as soybeans, and sunflowers.

OBJECTIVES

To determine if glyphosate has a role in kernel necrosis two studies were conducted. The first study was conducted to determine if glyphosate drift could cause pecan kernel necrosis. The second study was performed to determine if glyphosate applied directly to the trunk or a conventional application directed at the soil surface to control weeds, resulted in increased incidence and severity of pecan kernel necrosis.

MATERIALS AND METHODS

The following two studies were conducted at an orchard located in Marshall County near Madill, Oklahoma. The soil is a Madill fine sandy loam (coarse-loamy, mixed, active, nonacid, thermic, Typic Udifluvents). The trees were managed according to pecan production guidelines set forth by the orchard owner.

Glyphosate drift

Six 'Pawnee' trees were selected for the study. Trees were not irrigated. Single trees were randomly assigned as a treatment. Treatments included five volumes of glyphosate and a non-treated control (Table 6). In addition to the control on the treated trees nuts were collected from three trees without any glyphosate treatment to serve as a second control treatment. Trees served as blocks (3 replications) with twenty treated fruit clusters per tree (subsamples). Treatments were applied using a pipette to administer a 1 μL drop of a 1.5% glyphosate (N-(phosphonomethyl)glycine) (Glyphos Extra 48.7% a.i.

Cheminova) solution onto the fruit and leaves. When possible, a cluster size of three fruit was selected for each treatment otherwise, a two or four fruit cluster was selected. The treatments were applied to all fruit within a cluster. Treatments were applied on the same fruit and leaves each time glyphosate was applied. The treatment date was June 22 (sizing stage, average ovary length 16.62 mm and average ovule length 13.09 mm), August 22 (water stage, average ovary length 43.32 mm and average ovule length 26.08 mm) and September 6 (dough stage, average ovary length 44.20 mm and average ovule length 35.23 mm). Also, ten randomly selected fruit were collected when treatments were applied and measured for length and width of the outer pericarp, weight, ovule length and developmental stage (liquid endosperm, cellular endosperm, deposition of cotyledon storage materials). At shuck split nuts in all treated clusters and control clusters were harvested and kernel necrosis was graded for each nut using a 1 to 4 grading scale (Figure 3).

Treatments were as follows:

Treatments on the same tree:

a. 1 uL/per fruit- placed on shuck
b. 4uL/per fruit- a 1 uL drop placed on each quarter shuck
c. 5 1-uL drops on 1 leaf on a reproductive shoot (only 1 drop per leaflet)
d. 5 1-uL drops on each of 3 leaves on a reproductive shoot
e. 4 uL/per fruit- 1 uL drop placed on each shuck quarter and 5 uL drops on each of 3 leaves on a reproductive shoot (only 1 drop per leaflet)
f. None

Treatments on different tree:

g. None

Data was analyzed in SAS 9.2 software utilizing a mixed model for analysis of variance. Comparisons of treatment means was performed using protected least significant difference (LSD) test ($P<0.05$).

Glyphosate uptake

Treatments for this study included paraquat (Gramoxone Inteon 30.1 % a.i., Syngenta) serving as a control, glyphosate (Glyphos Extra 48.7 % a.i., Cheminova) used for vegetation control and vegetation control with paraquat with glyphosate applied to the lower 8-centimeters of the trunk with a hand sprayer (at a rate of 3.2 ounces per gallon of water) to run-off. Glyphosate was applied at a rate of 4.75 l/ha and paraquat at a rate of 3.5 l/ha. Treatments were repeated to control vegetation based on the producer's judgment on June 16, August 7, and September 6. Treatments were replicated twenty times using single-tree plots in a completely randomized design.

'Pawnee' trees selected for the study were 6 years-old measuring 12.45-centimeters (1.5 stdev) diameter above the ground. Ten fruit were randomly selected from adjacent trees and measured on each application date and at gel and dough stages. Length and width of fruit (shuck), pericarp (shell) and ovule (kernel) were measured, and weights of entire fruit were collected. The date of gel and dough stages was recorded. At shucksplit 60 nuts were collected from each tree. Weight per nut and percent kernel was determined and graded for necrosis on a scale 1 to 4 (Fig. 3).

Data was analyzed in SAS 9.2 software utilizing a mixed model for analysis of variance. Comparisons of treatment means was performed using protected least significant difference (LSD) test ($P<0.05$).

Results and Discussion

Glyphosate drift

Glyphosate applied at a rate of four 1 µl drops per fruit and four µl drops per fruit plus 5 1 µl drops on three leaves caused a significant incidence of fruit abortion as compared to the other treatments (Table 7). Glyphosate applied onto foliage and nuts did not significantly affect nut weight, percent kernel or percent kernel necrosis (Table 6). Nut weight among treatments ranged from 8.3 to 10.9 g/nut (Table 6); however, there was no significant difference among treatments. Percent kernel ranged from 49.1% to 58.4 % (Table 6) with no significant difference among treatments. Kernel necrosis ranged from 0% to 8.1%, but again there was no significant difference between treatments (Table 7).

Glyphosate uptake

Occurrence of kernel necrosis in the glyphosate treated trees was significantly higher (3.7 %) compared to treatments that used paraquat for vegetation control (1.3 %). Overall kernel necrosis severity was higher on the glyphosate treated trees (2.8 %) compared to trees treated with paraquat only (0.3 %). Glyphosate sprayed on the trunk of the trees but not on the ground did not increase the occurrence of kernel necrosis. (Table 8).

Conclusion

These studies indicate that glyphosate drift was not the cause of kernel necrosis in 'Pawnee' pecans. However, application of glyphosate to the soil around pecan trees increased the occurrence of kernel necrosis by 89% compared to using paraquat. Severe kernel necrosis was 65% higher on trees treated with a glyphosate application to the soil compared to trees treated with only paraquat. Glyphosate sprayed on the trunk of the trees but not on the ground did not increase the occurrence of kernel necrosis, indicating that glyphosate was not taken up by the trunk tissue. Glyphosate application to the tree trunk did not significantly increase the occurrence of kernel necrosis as compared to the paraquat treatment. Therefore, this study indicates that glyphosate applied to the soil is affecting kernel necrosis. It is not known if glyphosate is binding nutrients in the soil preventing the pecan tree to absorb essential nutrients, or if the glyphosate is being absorbed by the root system of pecan trees causing kernel necrosis. Kernel necrosis is a major concern for growers that have orchards where the malady has been detected. Further studies are needed to determine if glyphosate is the cause of kernel necrosis.

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Figure 3. Kernel necrosis grades of 'Pawnee' pecan. From left to right: grade 1-normal kernel; grade 2-darkening of testa in the dorsal groove at the basal (stem) end of the kernel; grade 3-necrotic tissue progressing outside of the dorsal groove at the basal end; and grade 4-necrosis encompasses the entire basal section of the kernel.

Figure 4. ‘Pawnee’ fruit with kernel necrosis collected during initial shuck split.

Table 6. Nut weight and kernel percentage of pecan (*Carya illinoinensis*) nuts from glyphosate drift study.

Treatment	Nut weight (grams)	Percent Kernel
None	9.3 a[z]	55.2 a[z]
1 1-µL drop[y]/fruit	8.6 a	56.2 a
4 1-µL drops[y]/fruit	9.5 a	58.4 a
5 1-µL drops[y] on 1 leaf	10.9 a	49.1 a
5 1-µL drops[y] on 3 leaves	8.3 a	55.9 a
4 1-µL drops[y]/fruit + 5 1-µL drops[y] on 3 leaves	9.2 a	57.2 a

[y] Concentration of Glyphos Extra 48.7% a.i.

[z] Means followed by the same letter are not significantly different by the protected LSD, 5% level.

Table 7. ‘Pawnee’ pecan kernel necrosis resulting from simulated glyphosate drift onto fruit and foliage at Madill, OK.

Treatment	Surviving nuts at shuck split (no.)	Any kernel necrosis (%)	Severe kernel necrosis (%)
None	195	5.0 a[z]	3.8 a[z]
1 1-µL drop[y] /fruit	198	3.5 a	1.9 a
4 1-µL drops[y] /fruit	35	0 a	0 a
5 1-µL drops[y] on 1 leaf	183	3.2 a	2.5 a
5 1-µL drops[y] on 3 leaves	151	4.1 a	1.4 a
4 1-µL drops[y] /fruit + 5 1-µL drops[y] on 3 leaves	57	8.1 a	3.9 a

[y] Concentration of Glyphos Extra 48.7% a.i.

[z] Means followed by the same letter are not significantly different by the protected LSD, 5% level.

Table 8. The influence of herbicide treatment on the incidence of kernel necrosis on 6-year-old ‘Pawnee’ trees at Madill, OK.

Treatment[y]	Any kernel necrosis (%)	Severe kernel necrosis (%)
Paraquat	1.3a[z]	0.3a[z]
Paraquat + glyphosate	1.8a	1.1a
Glyphosate[x]	3.7b	2.8b

[x] Glyphos Extra 48.7% a.i.

[y] Sixty nuts (120 kernels) were evaluated for necrotic symptoms per tree using a 1 (none) to 4 (severe) scale. Data reported as any necrosis (grades 2-4) and severe (grades 3 and 4).

[z] Means followed by the same letter are not significantly different by the protected LSD, 5% level.

CHAPTER IV

CONCLUSION

The research project discussed within this paper shows that using tree shelters during the establishment of pecans can increase total growth depending on the shelter used. Controlling vegetation around pecan trees has been shown to increase tree growth during establishment (Foshee et al., 1995; Patterson et al., 1990; Patterson and Goff, 1994; Smith et al., 2002; Wolf and Smith, 1999). In order for producers to achieve optimal pecan production, controlling vegetation is critical. The combination of allelopathy and competition for available resources is typically referred to as interference. To limit this interference, herbicides are typically used to control weeds surrounding young pecan trees (Foshee et al., 1997; Merwin and Stiles, 1994; Merwin et al., 1994; Norton and Storey, 1970; Patterson et al., 1990; Patterson and Goff, 1994). Glyphosate is the most widely used herbicide to control vegetation surrounding pecan trees. However, damage to trees can result from certain herbicides if direct contact occurs (Foshee et al., 2008). Tree shelters can be utilized to protect trees by eliminating contact with the trunk thus reducing the chance of herbicide damage. Tree shelters are used during establishment for many woody tree species and vineyards to increase growth of the plants (Burger et al., 1992; Frearson & Weiss, 1987; West et al., 1999; Hart, 1991; Potter, 1988, 1991). These shelters form a micro-climate around the plant and encourage faster growth. This study suggests that tree shelters can be used to protect newly established plants from herbicide contact. Some shelters caused an increase in temperature and relative humidity inside the shelters, while others resulted in reduced temperature and relative humidity. Tubex, Blue X and TP protectors had a higher average temperature than the control. Corrugated shelters had a lower high temperature than the control treatment. TP tube unvented and the Protex shelters increased the change in diameter of seedling pecan trees over the control. Protex Pro/Gro solid tube tree protectors had 65% larger diameter than trees grown in Clipper shelters. While the Protex and Snap n Grow increased the total growth of the seedlings over the control. The first year total shoot growth of trees grown using Snap n Grow tubes and Protex Pro/Gro solid tube tree protectors were 54% larger than Blue X shelters. Total shoot growth of trees grown using Protex Pro/Gro solid tube tree protectors were 64% larger than trees grown using Wholesale Ag shelters. Damaged tissue (caused by *Botryosphaeria sp.)* was observed on all treatments including the control and did not affect the growth of the seedlings. The trees seemed to outgrow the damage. As the bark starts to turn rough on the trunks the damaged tissue cannot be seen.

These studies indicate that glyphosate drift was not the cause of kernel necrosis in 'Pawnee' pecans. However, application of glyphosate to the soil around pecan trees increased the occurrence of kernel necrosis by 89% compared to using paraquat. Severe kernel necrosis was 65% higher on trees treated with glyphosate to the soil compared to trees treated with only paraquat. Glyphosate applied to only the trunk did not significantly increase the occurrence of kernel necrosis as compared to the paraquat treatment. Kernel necrosis is a major concern for growers that have orchards where the malady has been detected. Further studies are needed to determine if glyphosate contributes to the incidence of kernel necrosis.

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VITA

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Thesis: PERFORMANCE EVALUATION OF SEEDLING PECAN TREES USING COMMONLY SELECTED AND COMMERCIALLY AVAILABLE TREE SHELTERS AND THE EFFECT OF GLYPHOSATE APPLICATION ON PECAN KERNEL NECROSIS

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Scope and Method of Study: The objectives of these studies were to: 1) evaluate the growth and overall health of seedling pecan trees that were grown in a variety of commonly used physical barriers and commercially available tree protectors/shelters; 2) determine if the use of glyphosate around pecan trees increases the occurrence of kernel necrosis in ‘Pawnee’ pecans; 3) determine if glyphosate drift onto the leaves and/or nuts of ‘Pawnee’ pecans increases the occurrence of kernel necrosis.

Findings and Conclusions: TP tube unvented and the Protex shelters increased the diameter of seedling pecan trees over the control. Protex Pro/Gro solid tube tree protectors had 65% larger diameter than trees grown in Clipper shelters. While the Protex and Snap n Grow increased the total growth of the seedlings over the control. Total shoot growth of trees grown using Protex Pro/Gro solid tube tree protectors were 64% larger than trees grown using Wholesale Ag shelters. Damaged tissue (caused by *Botryosphaeria sp.)* was observed on all treatments including the control and did not affect the growth of the seedlings. Trees grown with the black drain pipe had the highest severity of damage, while the Tubex, Corrugated and Protex protectors had the lowest severity of damage. This study indicated that the use of the Protex protectors resulted in the greatest increase in diameter change, cumulative shoot growth and lowest damage severity compared to not using protection around the trunk of the trees during establishment.

These studies indicate that glyphosate drift was not the cause of kernel necrosis in ‘Pawnee’ pecans. However, application of glyphosate to the soil around pecan trees increased the occurrence of kernel necrosis by 89% compared to using paraquat. Severe kernel necrosis was 65% higher on trees treated with a glyphosate application to the soil compared to trees treated with only paraquat. Glyphosate sprayed on the trunk of the trees but not on the ground did not increase the occurrence of kernel necrosis, indicating that glyphosate was not taken up by the trunk tissue. Glyphosate application to the tree trunk did not significantly increase the occurrence of kernel necrosis as compared to the paraquat treatment. Therefore, this study indicates that glyphosate applied to the soil is affecting kernel necrosis.

ADVISER’S APPROVAL: Dr. Mike W. Smith