Pecan Shell Mulch Impact on 'Loring' Peach Tree Establishment and First Harvest

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SUMMARY. Pecan (*Carya illinoinensis*) shells are waste products that are occasionally used for mulch in ornamental landscape settings, yet most shell waste is left in piles near the shelling facility or discarded by other methods. If another use for this waste product could be developed, it may add income for pecan producers and provide peach (*Prunus persica*) growers with another option for weed control. A block of 'Loring' peach trees grafted onto 'Halford' rootstocks was planted at a spacing of 18 × 22 ft in Feb. 2005 at the Cimarron Valley Research Station near Perkins, OK, to determine the effect of pecan shell mulch on peach trees. Five treatments were imposed: no weed control except mowing (MOW), weed-free 6- × 6-ft area maintained with glyphosate herbicide (SPRAY), 6-ft × 6-ft × 2-inch deep mulch (TWO), 6-ft × 6-ft × 4-inch deep mulch (FOUR), and 6-ft × 6-ft × 6-inch deep mulch (SIX). Yields in 2008 were poorest in the MOW treatment (13.2 kg/tree and 93 fruit/tree). All other treatments did not differ. Soluble solids concentration as a measure of fruit quality and fruit weight was unaffected by treatment. Tree height, pruning weights, and trunk cross-sectional area were similar with the exception that MOW was lower for all three growth measurements beginning in 2007. Pecan mulch appears to have the potential to reduce soil pH. Foliar analysis for nitrogen (N), potassium (K), and zinc (Zn) showed treatment differences in 2006. No treatment differences were evident in 2007 and 2008 for K and Zn, but in 2008, FOUR had greater N than MOW. Tree mortality increased with pecan mulch depth. MOW, SPRAY, and TWO had little tree loss (0%–5%), whereas FOUR and SIX had 15% and 35% mortality, respectively. Tree mortality was attributed to record rains in 2007 coupled with longer soil moisture retention under the deeper mulch.

Weed management is a challenge in all fruit crops. Most weeds are controlled with appropriately labeled herbicides; however, sometimes herbicide application is not a viable option due to plant sensitivity, timing issues (i.e., preharvest intervals), or organic certification standards. Some of these weed issues may be mitigated by the appropriate use of mulches. Mulches provide several advantages over a bare-ground orchard floor because they conserve soil moisture [which may also lessen cold injury during droughty conditions (Smith, 2000)], insulate the soil against temperature extremes, and prevent soil erosion (Stefanelli et al., 2009). Mulches generally are beneficial to young fruit trees during establishment because of the weed barrier they provide (Baxter, 1970; Foshee et al., 1996, 1999; Lord and Vlach, 1973; Merwin et al., 1995).

Although mulches can be beneficial, there are potential negative ramifications of using mulches. Baxter (1970) found that mulching with 15 cm of straw applied every 2 years increased growth and production of peach and apple (*Malus* ×*domestica*) compared with cultivation or maintaining the orchard in pasture grasses, but the cost involved in maintenance and application of the straw was high, it posed a fire risk, it decomposed rapidly, and it could lead to waterlogging of the soil, potentially resulting in plant death. Overall though, he concluded that using mulch could result in a net overall profit from fruit sales due to increased harvests from mulched trees. Belding et al. (2004) noted that grass mulch applied without pre-emergence herbicides led to vole (*Microtus* spp.) problems, resulting in a 45% mortality rate of the peach trees. Plots maintained without mulch and with pre-emergent herbicides provided no cover for voles and resulted in no tree loss. A secondary issue is nutmeat fragments left in pecan shells used for mulch that may support toxigenic fungi. In one study, *Penicillium charlesii* was found to be harmful to wildlife and plant life in controlled laboratory and greenhouse situations (Cole et al., 1981).

Some mulches are organically derived products and others are manmade. Studies using shell mulches are few. Porter et al. (2005) used macadamia (*Macadamia integrifolia*) shell mulch on mature macadamia trees and found that the shell mulch led to increased root growth, larger trunks, and in drier conditions, higher nut-in-shell yield. Shell mulch could provide farmers with an additional organic orchard management tool. In Oklahoma, pecan shells are a waste product of the established pecan industry that could be used for mulch. Most of the available literature suggests that pecan shells can be an effective mulch (Black et al., 1994; Mexal et al., 2003; Skelly, 2005), but scientific data are lacking.

Mexal et al. (2003) reported that the New Mexico/western Texas pecan

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	$mg \cdot g^{-1}$	0.1
1	cbar	kPa	1
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	$inch^2$	cm^2	0.1550
0.4536	lb	kg	2.2046
0.0703	$lb/inch^2$	$kg \cdot cm^{-2}$	14.2233
28.3495	oz	g	0.0353
(°F − 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

industry produced roughly 59 million pounds of shells per year that could potentially be used as mulch or a container growing substrate. These uses could result in a monetary value of up to $2.6 million per year. Pecan shells are occasionally used as mulch in landscapes, but most shell waste is left in piles near the shelling facility or is discarded by other methods. If another use for this waste product could be developed, pecan shells might be considered a value-added product of the pecan production waste-product stream. The Oklahoma pecan industry depends primarily on native pecan production, but alternate-bearing tendencies lead to fluctuating annual yields (Wood et al., 2003). A product such as mulch that can be created independently of nut quality may provide an income source. The objective of this research was to evaluate the effect of pecan shells on peach tree productivity and nutrition, weed control, and soil properties.

Materials and methods

In Feb. 2005, a 'Loring' peach block was established at the Cimarron Valley Research Station in Perkins, OK. There were no known pathogens associated with this site and the site did not previously host a peach planting. This block was planted at a spacing of 18 × 22 ft on 'Halford' rootstock. 'Loring' was selected for testing pecan shell mulch because it is the most widely grown cultivar in Oklahoma. Trees were headed at planting to about 20 inches and pruned to an open vase system. The soil type was a Teller sandy loam (fine-loamy, mixed, thermic, Udic Argiustoll). The trees were managed according to Oklahoma Cooperative Extension Service recommendations during establishment (McCraw, 2003). Rainfall data (Table 1) were collected throughout the study using the Oklahoma Mesonet (Brock et al., 1995) on site. Irrigation was applied as needed in accordance with recommendations from Taylor and Rieger (2005) and was monitored twice weekly from May through October using Watermark sensors (Irrometer, Riverside, CA) at a depth of 6 inches below the soil surface. The pecan shell mulch originated from York Pecan Company (Foreman, AR) and was generally free of residual nut meat. A randomized complete block design with five blocks, four subsamples per block, and five treatments for a total of 20 trees per treatment (Table 2) was used. All plots were sprayed with fluazifop-p-butyl (Fusilade DX; Syngenta Crop Protection, Greensboro, NC) and paraquat (Gramoxone Inteon, Syngenta Crop Protection) before treatment. Glyphosate (RoundUp Original Max; Monsanto, St. Louis) was applied in SPRAY plots after weed ratings at a 2% solution via backpack sprayer. Treatments were first applied in May 2006. Plot length and width followed the recommendation of Smith et al. (2005) such that a 6-ft-diameter weed-free area was near optimal for pecan tree growth. All flowers and fruit were eliminated by frosts or freezes in 2006 and 2007. Samples for foliar nutrient analysis were taken each year in July from the middle leaf on current season's growth (100 leaves/sample). Leaves were rinsed in tap water, then in 2% (v/v) phosphorus (P)-free detergent, followed by 0.1 N hydrochloric acid and deionized (DI) water. Leaves were dried at 70 °C and ground to pass a 20-mesh screen. The macro-Kjeldahl method (Horowitz, 1980) was used for leaf elemental concentrations of N, a colorimetric measure for P (Olsen and Sommers, 1982), and atomic absorption spectroscopy for other elements. Fertilizer was applied based on foliar analysis from the prior year in Mar. 2007 and Mar. 2008. Soil samples were taken from each block in 2006 and each treatment within a block in 2007 and 2008 at depths of 6 and 12 inches. Soil samples were analyzed at the Oklahoma State University Soil, Water, and Forage Analytical Laboratory (SWFAL) by first oven drying at 60 °C for 24 h and ground to pass through a 2-mm sieve. Soil P was extracted with Mehlich 3 (Mehlich, 1984) and analyzed colorimetrically using a Quickchem 8000 (Mulvaney, 1996) automated flow-injection analyzer (LACHAT Instrument, Milwaukee). Soil organic carbon and total N were determined using a LECO Truspec dry combustion carbon analyzer (LECO, St. Joseph, MI) (Nelson and Sommers, 1996). Plant-available K was extracted using Mehlich 3 extraction solution and analyzed using inductively coupled plasma-atomic

Table 1. Monthly rainfall at the Cimarron Valley Research Station, Perkins, OK, from 2005–08.

	Rainfall (mm)[z]				
Month	2005	2006	2007	2008	30-year avg
January	87	20	39	16	32
February	47	5	16	61	42
March	15	51	134	97	78
April	14	113	71	118	89
May	71	80	258	159	145
June	136	57	350	130	112
July	54	53	176	114	67
August	225	43	58	39	70
September	84	68	65	42	106
October	51	38	91	54	85
November	0	39	16	124	67
December	2	66	29	28	47
Total	786	633	1,303	982	940

[z]1 mm = 0.0394 inch.

Table 2. Five treatments used under 'Loring' peach trees at the Cimarron Valley Research Station, Perkins, OK, with accompanying descriptions.

Name	Treatment[z]	Description[z]
MOW	Weedy control	No mulch, no herbicide, mow only
SPRAY	Herbicide	Glyphosate applied at 2% solution following weed ratings
TWO	2 inches deep	6 ft long × 6 ft wide × 2-inches deep mulch
FOUR	4 inches deep	6 ft long × 6 ft wide × 4-inches deep mulch
SIX	6 inches deep	6 ft long × 6 ft wide × 6-inches deep mulch

[z]1 inch = 2.54 cm, 1 ft = 0.3048 m.

emission spectroscopy (ICP-AES; Spectro Ciros, Fitchburg, MA). The soil pH was measured with a combination glass electrode in soil suspension containing 1:1 soil-to-DI water (Thomas, 1996).

Harvest was performed on a single-tree basis with no flower or fruit thinning during the harvest year (2008). Soluble solid concentrations (SSC) were measured on a random sample of one fruit from each tree from each block. All growth parameter measurements [tree height, trunk cross-sectional area (TCSA), and pruning weights] were measured during the dormant season. Yield efficiency (YE) was calculated as annual yield divided by TCSA. Average fruit weight was calculated as total harvest weight divided by the total number of fruit harvested on each tree. Trunk cross sectional area was measured in the dormant season at 6 inches above the graft union. Tree height was measured from ground level to the tallest shoot. Pruning fresh weights were collected for each tree before budbreak in 2007 and 2008. Weed density was rated in spring (April), summer (July), and fall (November) with herbicide application following rating to the SPRAY treatment. Ratings were based on visual observations on a 1 to 5 scale of approximate weed coverage within the mulched area, where 1 = 0% to 19% weed coverage, 2 = 20% to 39%, 3 = 40% to 59%, 4 = 60% to 79%, and 5 = 80% to 100%.

Analysis of variance was performed in JMP 7.0 (SAS Institute, Cary, NC) with mean separations determined by Tukey-Kramer honestly significant difference (HSD) at $P \leq 0.05$.

Results and discussion

Weed density. Weed density ratings in the MOW treatment were the highest, as would be expected (Table 3). By Apr. 2007, MOW was nearly completely covered with weeds, with SPRAY and TWO somewhat better, and FOUR and SIX nearly devoid of weeds. By July 2007, MOW plots were covered or nearly so. The SPRAY plots were treated after the April rating and thus had a lower rating for July. TWO had greater weed coverage than FOUR or SIX. In Nov. 2007, TWO increased in weed coverage, as the thinner layer of the mulch application began to settle and break down. By Nov. 2008, TWO provided no better weed control than MOW. Weed density in treatments FOUR and SIX increased by Nov. 2008. This can be attributed to the breakdown of the pecan mulch, indicating a need for reapplication. The discrepancy between the Nov. 2007 and Nov. 2008 SPRAY can be attributed to a missed application after harvest in 2008.

Tree growth. The pecan shell mulch treatments applied in May 2006 were not in place long enough to affect tree growth during the first year (Table 4). Tree height, pruning weights, and TCSA were smallest in the MOW treatment in 2007, but TCSA and tree height did not differ among SPRAY and the mulch treatments that year (Table 4). Smith et al. (2000) found that tree height and diameter of pecan trees were positively related to mulch area (1 or 2 m squares and 30 cm deep). They concluded that a 2-m-wide wood chip mulch application, 30 cm deep, in combination with 4-m-wide weed-free strip, resulted in the greatest tree growth. Tworkoski and Glenn (2001) reported that grass competition reduced growth and pruning weights. In the third year (2008), TCSA and average pruning weight were lowest in the MOW treatment and did not differ among other treatments, but average tree height in MOW was lower than trees in SPRAY or FOUR. This result suggested that SPRAY and FOUR were the best treatments for tree growth. The three pecan shell mulch treatments performed as well as or better than the SPRAY treatment and better than MOW in 2007, concurring with the conclusions of other studies that sod or weed competition reduces pruning weights (Glenn and Newell, 2008; Parker and Meyer, 1996). In 2008, SPRAY did not differ from any pecan shell mulch treatment.

Soil nutrition. Significant treatment effects for soil nutrients were not observed (data not presented); however, a significant treatment effect was observed in 2008 for soil pH (Table 5) at 6 inches. FOUR had a lower pH than MOW, but MOW was similar to TWO, SIX, and SPRAY. Soil pH decreased in

Table 3. Weed density ratings by treatment for spring, summer, and fall in 2 years following mulch application under 'Loring' peach trees.

	Weed density ratings (1–5 scale)[y]					
	2007			2008		
Treatment[z]	Apr.	July	Nov.	Apr.	July	Nov.
MOW	4.4 a[x]	5.0 a	5.0 a	5.0 a	5.0 a	5.0 a
SPRAY	3.1 b	1.3 c	1.1 d	3.4 b	1.8 cd	4.1 bc
TWO	2.1 c	2.7 b	3.7 b	3.9 b	4.4 b	4.5 ab
FOUR	1.1 d	1.1 c	1.7 c	1.7 c	2.0 c	3.6 cd
SIX	1.0 d	1.1 c	1.2 d	1.1 d	1.4 d	3.0 d

[z]MOW = mow only, SPRAY = glyphosate herbicide spray, TWO = 2-inch-deep mulch, FOUR = 4-inch-deep mulch, SIX = 6-inch-deep mulch; 1 inch = 2.54 cm.
[y]1 = 0% to 19% weed coverage, 2 = 20% to 39% weed coverage, 3 = 40% to 59% weed coverage, 4 = 60% to 79% weed coverage, 5 = 80% to 100% weed coverage.
[x]Means within columns followed by the same letter do not significantly differ as determined by Tukey-Kramer honestly significant difference (HSD) at $P \leq 0.05$.

Table 4. Growth parameters measured over 3 years for 'Loring' peaches at the Cimarron Valley Research Station, Perkins, OK.

	TCSA (cm^2)[y]			Avg tree ht (m)[x]			Avg pruning wt (kg/tree)[x]	
Treatment[z]	2006	2007	2008	2006	2007	2008	2007	2008
MOW	0.99[w]	5.73 b	18.64 b	1.28	2.00 b	2.82 b	1.05 c	4.10 b
SPRAY	1.01	7.90 a	29.92 a	1.32	2.15 a	3.18 a	1.71 b	7.73 a
TWO	0.95	9.21 a	29.20 a	1.28	2.18 a	3.03 ab	2.02 ab	7.73 a
FOUR	0.86	8.94 a	28.92 a	1.27	2.13 a	3.06 a	2.26 a	7.39 a
SIX	0.96	8.84 a	28.90 a	1.31	2.12 a	3.05 ab	2.05 ab	8.34 a

[z]MOW = mow only, SPRAY = glyphosate herbicide spray, TWO = 2-inch-deep mulch, FOUR = 4-inch-deep mulch, SIX = 6-inch-deep mulch; 1 inch = 2.54 cm.
[y]Trunk cross-sectional area; 1 cm^2 = 0.1550 $inch^2$.
[x]1 m = 3.2808 ft, 1 kg = 2.2046 lb.
[w]Means within columns followed by the same letter do not significantly differ as determined by Tukey-Kramer honestly significant difference (HSD) at $P \leq 0.05$. Columns without letters following means were not significantly different.

Table 5. Soil pH properties by year and soil depth for all treatments over 2 years under 'Loring' peach trees at the Cimarron Valley Research Station at Perkins, OK.

	pH			
	2007		2008	
Treatment[z]	Depth (6 inches)[z]	Depth (12 inches)	Depth (6 inches)	Depth (12 inches)
MOW	6.32[y]	6.42	6.28 a	6.32
SPRAY	6.24	6.22	6.06 ab	6.14
TWO	6.04	6.32	6.00 ab	6.24
FOUR	6.06	6.26	5.88 b	6.22
SIX	6.12	6.30	5.92 ab	6.08

[z]MOW = mow only, SPRAY = glyphosate herbicide spray, TWO = 2-inch-deep mulch, FOUR = 4-inch-deep mulch, SIX = 6-inch-deep mulch; 1 inch = 2.54 cm.
[y]Means within columns followed by the same letter do not significantly differ as determined by Tukey-Kramer honestly significant difference (HSD) at $P \leq 0.05$. Columns without letters following means were not significantly different.

pecan shell treatments throughout the study. Average pretreatment pH taken in 2006 at 6 and 12 inches was 6.82 and 6.32, respectively. Average post-treatment pH overall treatments decreased in 2007 to 6.16 and 6.30 at 6 and 12 inches, respectively. In 2008, pH declined further to 6.03 and 6.20 at 6 and 12 inches, respectively. The decrease in pH provided by the pecan shell mulch could improve plant growth and quality of fruit species such as blueberries (*Vaccinium* spp.) that require acid soils, while reducing or eliminating the amount of added sulfur (S) needed to reduce pH.

TREE NUTRITION. Foliar analysis revealed no treatment effect for S, calcium (Ca), nickel (Ni), copper (Cu), manganese (Mn), iron (Fe), and magnesium (Mg) (data not presented), and all were within the sufficiency range (Lockwood et al., 2005). Data for P were only available in 2006 (data were lost for 2007 and 2008) and significant differences occurred between treatments (Table 6), with the SIX treatment providing the most P and MOW the least. Phosphorous appeared to trend higher as mulch depth increased. Pecan shell mulch treatments increased N, K, and Zn content in the foliage during the first year (Table 6). The effect lasted into 2007 for N in the SPRAY treatment, but by 2008, most treatments were similar to MOW with the exception of FOUR. Foliar K and Zn content did not differ between pecan shell treatments and MOW or SPRAY in 2007 or 2008. Foliar Zn content was highest in the deepest mulch treatments during first year, but did not differ in the following years.

FRUIT YIELD. First harvest yield data showed that the weedy control treatment (MOW) was significantly less than two of the four weed-free treatments (SPRAY and FOUR) with 13.1 kg/tree and 93 fruit/tree (Table 7), a finding that concurs with previous studies (Glenn and Newell, 2008; Tworkoski and Glenn, 2001). Pecan shell mulch treatments and SPRAY did not differ. Yield efficiency, soluble solid concentration, and average fruit weight did not differ among treatment (P = 0.1003, 0.3328, and 0.6688, respectively) (Table 7). Competition from weeds did not affect fruit quality, but retarded yields and fruit number per tree through competition for moisture and nutrients or potential allelopathic effects as observed in other studies (Glenn and Newell, 2008; Smith et al., 2001; Weller et al., 1985).

TREE MORTALITY. Tree mortality increased with the depth of pecan mulch. SPRAY had no tree loss and MOW and TWO had little tree loss (5%), whereas FOUR and SIX had an unacceptable mortality rate (15% and 35%, respectively). Peach has little tolerance for waterlogged soils, with tree death reported in as little as 2 d of inundation (Kozlowski, 1997). During June and July 2007, trees had a soil moisture status of less than 10 cbar for up to 6 weeks (data not presented), which would limit oxygen availability to the roots (Taylor and Rieger, 2005). Thus, the primary reason for mortality was likely due to record rainfall in 2007 coupled with the longer moisture retention from deeper mulch (Baxter, 1970; Black, 1963).

Pecan shell mulch could provide peach or other fruit producers with another option for weed control; however, mulch that is applied too deep (6 inches) or too thin (2 inches) may create problems. Mulch that is too deep may cause soil waterlogging in wet years, and thin applications will need to be reapplied every other year to maintain effective weed control. Although untested in this experiment, pecan shells have significant amounts of phenolic compounds (Villarreal-Lozoya et al., 2007) that may also lead to adverse allelopathic effects with long-term use. From this experiment, it appears that the FOUR treatment of pecan shell mulch provided a long-lasting benefit for weed control and had as good or better tree

Table 6. Effect of treatment on nutrient concentration of foliar phosphorus (P), nitrogen (N), potassium (K), and zinc (Zn) collected in July 2006–08 for 'Loring' peach trees.

	2006				2007			2008		
Treatment[z]	P (%)	N (%)	K (%)	Zn ($mg \cdot g^{-1}$)[y]	N (%)	K (%)	Zn ($mg \cdot g^{-1}$)	N (%)	K (%)	Zn ($mg \cdot g^{-1}$)
MOW	0.162 d[x]	2.77 c	1.97 c	12.48 c	2.55 b	2.42	16.64	2.37 b	2.02	12.40
SPRAY	0.196 c	3.37 b	2.31 b	14.36 bc	3.04 a	2.60	19.08	2.50 ab	2.00	12.40
TWO	0.208 bc	3.63 a	2.57 ab	15.25 b	2.86 ab	2.50	18.52	2.44 ab	2.06	11.98
FOUR	0.214 ab	3.58 ab	2.68 a	17.82 a	2.79 ab	2.58	17.00	2.59 a	2.02	13.54
SIX	0.230 a	3.64 a	2.70 a	19.50 a	2.82 ab	2.74	18.34	2.43 ab	2.14	12.78

[z]MOW = mow only, SPRAY = glyphosate herbicide spray, TWO = 2-inch-deep mulch, FOUR = 4-inch-deep mulch, SIX = 6-inch-deep mulch; 1 inch = 2.54 cm.
[y]1 $mg \cdot g^{-1}$ = 0.1%.
[x]Means within columns followed by the same letter do not significantly differ as determined by Tukey-Kramer honestly significant difference (HSD) at $P \leq 0.05$. Columns without letters following means were not significantly different.

Table 7. 'Loring' peach tree fruit yield, yield efficiency, number of fruit per tree, average fruit weight, and soluble solids concentration (SSC) by treatment in 2008.

Treatment[z]	Avg yield (kg/tree)[y]	Yield efficiency ($kg \cdot cm^{-2}$ TCSA)[x]	Avg fruit per tree (no.)	Avg fruit wt (g)[w]	SSC (%)
MOW	13.1 b[v]	0.22	93 b	141	12.7
SPRAY	21.2 a	0.28	165 a	128	11.7
TWO	20.1 ab	0.26	150 ab	134	12.1
FOUR	26.4 a	0.33	195 a	135	12.3
SIX	20.0 ab	0.26	156 ab	128	13.0

[z]MOW = mow only, SPRAY = glyphosate herbicide spray, TWO = 2 inches deep mulch, FOUR = 4 inches deep mulch, SIX = 6 inches deep mulch; 1 inch = 2.54 cm.
[y]1 kg = 2.2046 lb.
[x]1 $kg \cdot cm^{-2}$ = 14.2233 $lb/inch^2$, TCSA = trunk cross-sectional area.
[w]1 g = 0.0353 oz.
[v]Means within columns followed by the same letter do not significantly differ as determined by Tukey-Kramer honestly significant difference (HSD) at $P \leq 0.05$. Columns without letters following means were not significantly different.

growth and fruit yield as the herbicide treatment; however, tree mortality was higher than the MOW, SPRAY, and TWO treatments.

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