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Mature Pecan Orchard Floor Vegetation Management: Impacts on Tree Water Status, Nutrient Content, and Nut Production

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***Abstract*. Pecan [*Carya illinoinensis* (Wangenh.) K. Koch] growers are advised to control orchard floor vegetation when establishing new orchards, but there is not a set recommendation for vegetation control in mature orchards. The objective of this study was to measure the effect of orchard floor vegetation on water and nitrogen (N) status of flood-irrigated mature pecan trees. Four treatments studied were: completely vegetated orchard floor, vegetation-free inner area directly under the tree canopy with vegetation in the outer area, completely vegetation-free, and vegetated inner area under the canopy with a vegetation-free outer area. Treatments were organized as a 2 × 2 factorial structure with inner and outer treatment factors, both with levels vegetated and vegetation-free. Soil moisture and tree midday stem water potential (MSWP) were measured during irrigation cycles to evaluate the development of water stress in the pecan trees. Soil moisture data showed a significant outer main effect when the soil in the entire orchard was the driest, that is, just before irrigation events. Areas with vegetation cover that were exposed to full sun were significantly drier than shaded vegetated areas and vegetation-free areas in the orchard floor. However, this was not correlated with differences in tree water status as indicated by MSWP. Leaf tissue and soil analyses showed no significant differences in N concentrations among treatments in either year. Treatments with orchard floor vegetation in the outer area had significantly higher yield efficiency and marginally significant improvements in percent kernel fill and number of nuts per kilogram. Our findings suggest that there may be more benefits to maintaining orchard floor vegetation in mature orchards than were previously acknowledged.**

The pecan industry is thriving in the western United States (west Texas, New Mexico, Arizona, and California) totaling almost 27,500 ha with over 16,000 ha in New Mexico alone (USDA, National Agricultural Statistics Service, 2009). However, water resources are limited and expensive in this semiarid or arid region. Consumptive water use requirements of pecan orchards are high, at more than 1.5 m annually (Miyamoto, 1983; Sammis et al., 2004). Increases in pecan acreage are placing new demands on irrigation districts and groundwater supplies throughout the Southwest.

Orchard floor management practices of pecan growers in the southwestern United States are varied, ranging from only periodic mowing of vegetation to complete vegetation control through herbicides or cultivation. The presence of orchard floor vegetation has benefits including reduced soil erosion, reduced surface crusting, which leads to improved water infiltration, and improved orchard access by heavy machinery (Elmore, 1989; Folorunso et al., 1992; MacRae and Mehuys, 1985). However, pecan harvest operations are hindered by excess orchard floor vegetation and vegetation may also compete with trees for nutrients and water (Merwin and Ray, 1997; Radosevich et al., 2007).

Many studies demonstrated substantial tree growth and yield reductions associated with floor vegetation of young pecan orchards in the humid southeastern United States (Faircloth et al., 2007; Foshee et al., 1995; Patterson and Goff, 1994; Patterson et al., 1988, 1990; Smith, 2011; Smith et al., 2002, 2005). In Patterson and Goff's 1994 study that examined newly planted trees for 8 consecutive years, trees subjected to total chemical vegetation control produced over five times more pecans in the last 3 years of the study than trees competing with vegetation. This difference was attributed to higher potassium levels in total vegetation control treatments. Goff et al. (1991) also showed that orchard floor vegetation can affect nutrient status of immature trees as a result of competition. However, there have been no studies investigating the effects of vegetation management on mature pecan orchard productivity under the arid growing conditions of the southwestern United States, where water stress and N deficiency are likely to be primary factors limiting pecan orchard productivity.

The optimization of irrigation water use and fertilizer efficiency in mature orchards requires a better understanding of the impact of orchard floor vegetation on trees. Therefore, the objective of this study was to assess the effect of orchard floor vegetation on mature pecan trees by monitoring soil moisture, leaf and soil N concentrations, tree water status, and orchard productivity in plots with different amounts of vegetative cover. The null hypothesis of this study was that floor vegetation would have no effect on N status, water status, nut yield, or nut quality of mature pecan trees.

Materials and Methods

Orchard characteristics and weed composition. The study orchard was located in Mesilla Valley, NM (lat. 32.24°, long. –106.76°, elevation 1179 m). The experimental trees were ≈35-year-old commercially managed 'Western' (syn. 'Western Schley') pecan trees spaced at 13 × 15 m in Harkey-loam soil (coarse silty, mixed, calcareous, thermic typic Torrifluvents) with a pH of 7.8 (NRCS Soil Survey, United States Department of Agriculture, 2010). Randomly distributed 'Wichita' trees served as pollenizers in the orchard. This area of New Mexico has an average freeze-free growing period of 230 d with average annual precipitation of 240 mm. A nearby weather station (New Mexico State Climate Office, 2011) at New Mexico State University Fabian Garcia Science Center, 5.5 km away, reported 6.8 cm

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of rainfall during the experiment in 2009 and 8.0 cm of rainfall in 2010 (Figs. 1C–2C).

High temperatures during both experimental seasons were within the normal range for this region. In 2009 and 2010 the highest temperatures for data collection days were 38 and 41 °C, respectively (New Mexico State Climate Office, 2011). The orchard was flood-irrigated with water from the Rio Grande eight times per year in 2009 and 2010 with ≈15.2 cm of water per irrigation (Figs. 1C–2C). Irrigations were scheduled at 3- to 5-week intervals depending on rainfall, temperature, and tree growth stage at the discretion of the orchard owner. Insecticide application, fertilization, and periodic mowing were all controlled by the orchard owner. Nitrogen was applied in the irrigation water during the growing season as urea–ammonium nitrate (UAN, 32% N) solution at a rate of 54.3 kg N/ha divided into three and four applications in 2009 and 2010, respectively. Weed composition consisted of mainly annual species. Palmer amaranth (*Amaranthus palmeri* S. Wats.), barnyardgrass (*Echinochloa crus-galli* L.), and green foxtail (*Setaria viridis* L.) dominated the orchard with many other annual species present in lower densities. Hare barley (*Hordeum leporinum* L.) and London rocket (*Sisymbrium irio* L.) were the predominant species during the winter season. The perennial species present in the orchard were field bindweed (*Convolvulus arvensis* L.), purple nutsedge (*Cyperus rotundus* L.), broadleaf plantain (*Plantago major* L.), curly dock (*Rumex crispus* L.), silverleaf nightshade (*Solanum elaeagnifolium* Cav.), perennial sowthistle (*Sonchus arvensis* L.), and dandelion (*Taraxacum officinale* F. H. Wigg.). Broadleaf plantain was the only perennial weed species present throughout the orchard with all of the other populations of perennial weed species being found in small localized patches within the orchard.

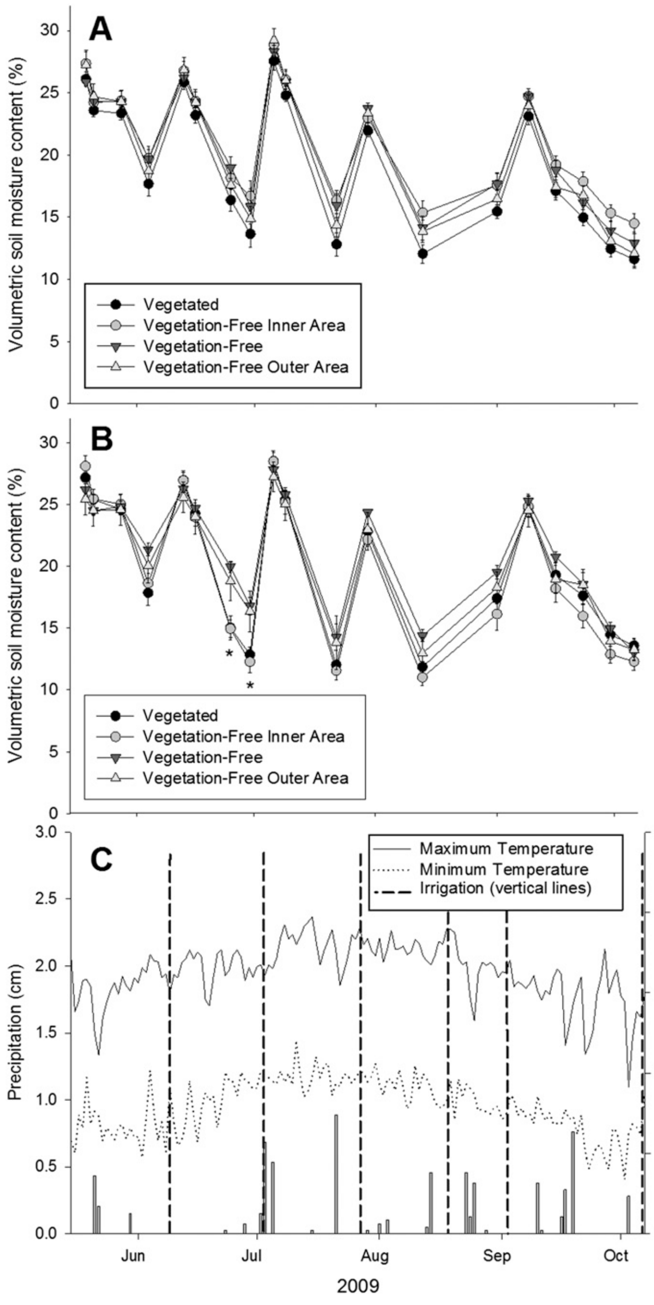

Fig. 1. Volumetric soil moisture for each of the four treatment levels collected from inner (**A**) and outer (**B**) soil moisture probe location through 2009 growing season. Soil moisture data are means ± SE. Dates marked with an asterisk (*) indicate significant ($P \leq 0.05$) outer vegetation factor by probe location interaction with vegetated outer location drier than vegetation-free outer location. Precipitation (bars) and daily maximum and minimum temperature data are from a nearby weather station (**C**). Irrigation events (vertical lines) consisted of ≈15.2 cm each (**C**).

Weed species did not provide a consistent amount of vegetative groundcover throughout the study. The orchard owner mowed the vegetation periodically (six times in 2009 and four times in 2010) and there were areas, especially in May 2010, when some of the vegetated plots did not have complete vegetation cover. Sometimes the cut vegetation after mowing acted as a mulch, suppressing emergence and regrowth of vegetation. Nevertheless, at all times throughout both growing seasons, weedy vegetation provided greater than 50% groundcover and clear visual distinction could be made between vegetated and vegetation-free treatment areas.

Experimental design. Four replications of four vegetation management treatments organized as a 2 × 2 factorial treatment structure (Fig. 3) were arranged as a completely randomized design. Each experimental unit consisted of two sample trees surrounded by 10 buffer trees (buffer trees underwent the same treatment as the sample trees in each unit). Treatment factors were inner and outer, both with vegetated and vegetation-free levels. Treatment 1 (vegetated control) had vegetation (i.e., weeds) covering the entire treatment area (i.e., both the inner and outer factors were vegetated). Treatment 2 (vegetation-free inner) had a vegetation-free area 6 × 6 m around the trees and vegetation was allowed to grow outside of that vegetation-free square (i.e., inner factor was vegetation-free and outer factor was vegetated). In Treatment 3 (vegetation-free control), vegetation was controlled in the entire treatment area (i.e., both inner and outer factors were vegetation-free). Treatment 4 (vegetation-free outer) had a vegetated area 6 × 6 m directly under the trees and vegetation was controlled outside of that square (i.e., inner factor was vegetated and outer factor was vegetation-free).

Vegetation-free areas were maintained during the growing seasons of 2009 and 2010 using a combination of chemical and manual weeding. The post-emergent herbicide, glyphosate [Makaze®, *N*-(phosphonomethyl)-glycine; Loveland Products, Greeley, CO] was applied at 2.24 kg a.i./ha three times in 2009 (15 Apr., 29 July, 21 Sept.) and three times in

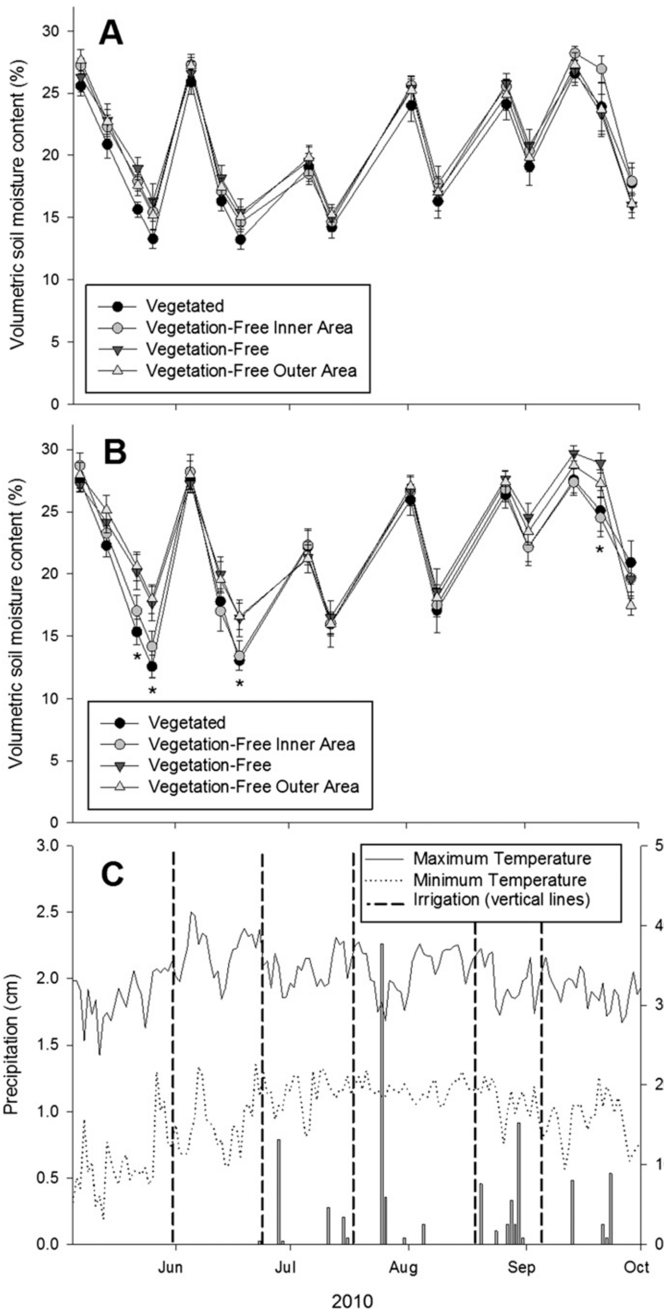

Fig. 2. Volumetric soil moisture for each of the four treatment levels collected from inner (**A**) and outer (**B**) soil moisture probe location through 2010 growing season. Soil moisture data are means ± SE. Dates marked with an asterisk (*) indicate significant ($P \leq 0.05$) outer vegetation factor by probe location interaction with vegetated outer location drier than vegetation-free outer location. Precipitation (bars) and daily maximum and minimum temperature data are from a nearby weather station (**C**). Irrigation events (vertical lines) consisted of ≈15.2 cm each (**C**).

2010 (6 Apr., 25 May, 29 Sept.). Each year additional spot treatments of glyphosate were applied, as needed, with backpack sprayers. The pre-emergent herbicide, pendimethalin [Prowl H_2O®, *N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine; BASF Corporation, Research Park, NC], was applied twice in 2009 (15 to 16 Apr., 29 to 30 July) at 4.26 kg a.i./ha. Vegetation was also manually removed between herbicide applications in 2009 and 2010. Herbicides were not applied in treatment areas during winter, 2009–2010, but the late-season pendimethalin application provided residual weed control that extended through the winter season.

Data collection and statistical analysis. Soil moisture and midday stem water potential were measured at weekly intervals after each irrigation event for a total of 21 times in 2009 and 17 times in 2010. Soil moisture was measured as volumetric water content and reported as percent soil moisture using a time domain reflectometry system (TRASE System I; ICT International, Armidale, Australia). Twenty-centimeter-long waveguide probes were buried vertically 30.5 cm deep to measure volumetric soil moisture content over the range of 10.5 cm to 30.5 cm deep. Both the pecan roots and the weed roots were expected to be most abundant in that part of the soil profile (Miyamoto, 1983; Ross and Lembi, 2009). Sixty-four waveguide probes were placed throughout the orchard, four per experimental unit. One sensor was placed outside of the 6 × 6-m area immediately surrounding the tree so that it received maximum sun exposure (4.8 m from tree trunk) and one sensor was placed inside of that area where it was predominantly shady (2 m from tree trunk). Within each experimental unit, the probe readings were averaged based on location: inner or outer.

Midday stem water potential (i.e., water potential of dark-bagged leaves at midday) was measured at 1-week intervals after each irrigation using a Scholander Pressure Chamber (Model 615; Plant Moisture Stress, Albany, OR) to directly assess tree water status. Measurement of water potential at midday is a reliable method to detect tree water status (Shackel et al., 1997). MSWP data were collected between 1130 HR and 1500 HR using subsamples of two measurements per sample tree, giving a total of four subsamples per experimental unit. Sample leaves were selected from the middle of fruit-bearing, shaded branches in the lower canopy. Each sampled leaf was first placed in an aluminum bag and left on the tree for a minimum of 45 min to allow leaf water potential to equilibrate with that of the stem, thus estimating tree water status.

To assess the impact of orchard floor vegetation on N availability, leaf and soil samples were analyzed for total N and nitrate-N concentration, respectively, using a LECO FP528 Nitrogen Analyzer (St. Joseph, MI) and a HACH sensION4 ISE meter with aluminum sulfate extract (Loveland, CO). Leaf samples from each sample tree (Aug. 2009 and Sept. 2010) and soil samples from each plot (June 2009 and Oct. 2010), 0–15 cm deep, were collected following New Mexico State University Cooperative Extension Service guidelines (Glover and Baker, 2000; Herrera, 2000).

A 13 × 25-m rectangular area was marked out on the ground surrounding each set of sample trees to measure yield. After shaking the two sample trees within each experimental unit, the nuts were harvested and weighed. In 2009, the 13 × 25-m rectangle was divided in half so that yield was measured per individual tree but pooled by experimental unit for analysis. In 2010, nut yield data were collected from each experimental unit (i.e., with yield from the two sample trees in each plot pooled) using a pecan harvester (Savage Model 8042, Madill, OK). To account for varying levels of debris and leaf litter in the piles of nuts after they had been mostly cleaned by blowers and rakes, 1- to 1.5-kg samples from the piles of nuts and debris were removed from the orchard. These samples were later cleaned, reweighed, and the percentage of clean weight vs. the original sample weight was used to estimate total clean nut weight from each experimental tree.

These same samples were then counted, cracked, and the nut meat weight was determined for harvest quality data. Nut quality factors included percent kernel in both 2009 and 2010 and number of nuts per kilogram in 2010.

Data were analyzed using SAS PROC MIXED software Version 9.2 (SAS Institute, Cary, NC). Significance was defined as $P \leq 0.05$ for all analyses. However, differences were acknowledged as "marginally significant" when $P \leq 0.10$. Soil moisture and soil N data were analyzed by respective sample date in a split-plot experimental design with the whole plot factor being the treatments in a 2 × 2 factorial structure in which the inner and outer measurements were both either vegetated or vegetation-free. Soil moisture probe location (inner or outer) was the split-plot factor. Leaf N and MSWP were also analyzed by date using analysis of variance for a 2 × 2 factorial structure. For MSWP, there were two layers of subsampling: two trees within each experimental unit and two leaves sampled per tree per collection date. Subsampling was recognized by including appropriate random effects in the model. For yield parameters, experimental unit averages were analyzed as a 2 × 2 factorial treatment structure with year as a repeated factor (except for number of nuts per kilogram, which was only recorded in 2010). An unstructured covariance was fit to account for covariances and possible nonconstant variance between the repeated measures (years). When an effect was significant, least significant difference was used for post hoc pairwise comparisons applied to the highest order significant effect.

Results and Discussion

Soil moisture. On three dates in 2009 and nine dates in 2010 the probe location main effect was statistically significant (inner vs. outer probes). All were drier at the inner probe location except one date in 2009. The three-way interaction (outer vegetation factor, inner vegetation factor, and probe location) was statistically significant on four occasions in 2009 and two in 2010. Post hoc comparisons showed little consistency in the pattern of differences, although most differences could be characterized as simple probe location effects.

For soil moisture, there was never an inner vegetation factor main effect (Figs. 1A–2A). However, the outer vegetation factor main effect was significant twice in 2010 with outer vegetated plots being significantly drier. Also, there was a significant two-way interaction between the outer vegetation factor and probe location on six occasions across both years (Figs. 1B–2B). In these cases, the vegetated outer location was consistently drier than the vegetation-free outer location. Outer vegetation main effects and outer vegetation factor-by-probe-location interactions tended to occur at the end of an irrigation dry-down cycle and in the hottest, driest parts of the growing season. Furthermore, when the interaction was significant, soil moisture differences were detected at the outer probe location where the moisture probes were placed outside of the tree canopy and exposed to full sun. For example, on 18 June 2010, volumetric soil moisture in vegetated outer areas was 13.2% vs. 16.5% volumetric soil moisture in vegetation-free outer areas (Fig. 2B). Similar results of reduced soil moisture resulting from grass competition were found in a study of mature peaches in West Virginia (Tworkoski and Glenn, 2001).

Tree water status. In the present study, treatment differences in soil moisture did not correlate with differences in tree water status as indicated by MSWP (Fig. 4). Regardless of treatment, the water status of the all of the sampled trees in this study did drop through each dry-down cycle, showing that the trees were not receiving adequate water from roots reaching the water table to maintain tree water status. Therefore, although the transpiration of orchard floor vegetation reduced available water in the soil at the outer probe location at the end of a dry-down cycle, the level of competition for water with the mature trees was not sufficient to detect significant differences in the water status of the mature pecan trees in this study.

Interestingly, although there were no significant interactions in either year, at the end of the 2010 experimental season, there were significant outer vegetation main effects in

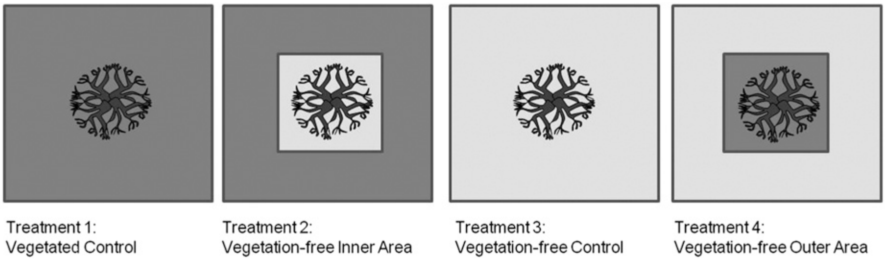

Fig. 3. Four treatments of varying vegetated area surrounding mature pecan tree. Smaller square that designates inner area is 6 × 6 m. Tree image adapted with author permission from Welker and Glenn (1991).

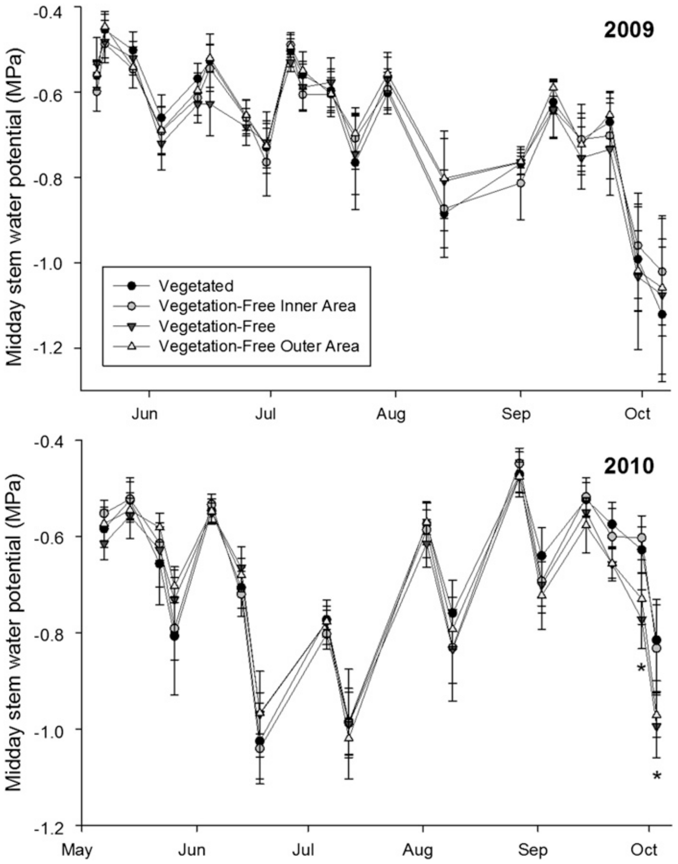

Fig. 4. Midday stem water potential (tree water status) for each of the four treatment levels through growing season of 2009 and 2010. Midday stem water potential data are means ± SE. Dates marked with an asterisk (*) indicate significant ($P \leq 0.05$) outer vegetation factor main effects. Note that Y-axis does not extend to zero.

MSWP. Trees with vegetation in the outer area had a greater water potential (less stress) than the trees without vegetation in the outer area (Fig. 4). On 29 Sept. and 3 Oct. 2010, MSWP means for trees with vegetation in the outer area were –0.62 MPa and –0.82 MPa, respectively, compared with –0.75 MPa and –0.98 MPa, respectively, for trees without vegetation in the outer area. The cause for this difference is unknown, but it is possible that at the end of the growing season, annual vegetation transpiration slowed, acting as a living mulch, thereby preserving soil moisture and increasing permeability that favorably affected tree water status (Folorunso et al., 1992). This suggests that pecan growers may see benefits by allowing some vegetation cover in their orchards at the end of the summer season. In a similar study on both immature and mature almond (*Prunus dulcis* Mill.) trees in California (Pritchard et al., 1990), cover crops as an orchard floor management option resulted in greater water infiltration rates in the soil compared with a clean orchard floor. Additionally, Pritchard et al. (1990) suggested that increased shading with a larger root area in the mature orchard as compared with the immature orchard was the reason for greater orchard floor management treatment differences in the young orchard than in the mature orchard.

Nitrogen competition. There were no significant differences among treatments in amounts of nitrate in soil samples or N concentration in leaf samples (data not shown). Similarly, Wright et al. (2003) found no effect of orchard floor vegetation in a young citrus (*Citrus limon* L., *Citrus sinensis* L.) orchard on citrus leaf nutrient concentration. In the same study, however, the cover crop and weedy treatments did have higher soil N concentration. It should be noted that the orchard in the current experiment was a commercial orchard where the orchardist applied fertilizer as needed (including N in the form of liquid UAN mixed in the irrigation water several times in 2009 and 2010). At a range of 2.5% to 2.7%, leaf N levels remained within the normal range for pecan leaves in New Mexico. To detect N competition between orchard floor vegetation and pecan trees, the N supply would have to be low enough to affect the N concentration in the leaves. It appears that, at the applied rates, there was sufficient N in the soil to supply both the orchard floor vegetation and the trees.

Nut production and quality. The most productive orchards in the Mesilla Valley have average annual in-shell nut yields of 2500–3000 kg·ha^{-1}. Average yield for this experimental orchard during the study exceeded 3000 kg·ha^{-1}. No significant differences for year-by-factor interaction between treatments or as a result of location of vegetated areas were found in harvest yield data (Table 1). This measure of harvest yield did not take into account the overall size of the tree, so yield efficiency rating was also calculated per experimental unit. Yield efficiency (g·cm^{-2}) is a measure of tree nut weight per square centimeter of trunk cross-sectional area. For yield efficiency, outer main effects were significant (Table 1). Vegetated outer areas had higher yield efficiency (lsmeans ± SE: 54.39 ± 2.58 g·cm^{-2} for vegetated vs. 46.37 ± 2.58 g·cm^{-2} for vegetation-free). These results differ from results of a study of mature sour cherry (*Prunus cerasus* L.) tree yield efficiency in which alternative orchard floor managements did not affect yield efficiency ratings (Sanchez et al., 2003).

Percent kernel fill, a measure of the amount of nut meat in the shell, demonstrated a marginally higher ($P = 0.0861$) percentage for the treatments with vegetation in the outer area (55% kernel) than for the treatments that were vegetation-free in the outer area (54% kernel) (Table 2). Furthermore, in 2010, number of nuts per kilogram had marginally significant inner and outer main effects (Table 2). Inner vegetated had 6.9 ± 3.7 fewer nuts per kilogram and outer vegetated had 7.35 ± 3.7 fewer nuts per kilogram, meaning that the nuts were bigger and therefore more desirable with vegetation. Similar results were found in a 15-year study of orchard floor management systems in apples (*Malus domestica* Borkh.). Atucha et al. (2011) examined effects of four apple orchard floor management practices: vegetation-free with the use of pre-emergent herbicides, vegetation-free with the use of post-emergent herbicides, a sod cover crop, and hardwood bark mulch. In the first years of orchard establishment, sod groundcover significantly reduced growth and yield of the young trees. However, as the trees matured, the effect of the cover crop became less remarkable. At the end of the study, when the apple trees were mature, there was no significant effect of orchard floor management treatment on tree growth or yield. These results were attributed to the ability of the trees to adapt to or avoid sod competition over time.

Despite reducing the soil moisture at the end of dry-down cycles in the hottest time of the summer in the sunniest parts of the orchard, orchard floor vegetation, particularly outer vegetation, had a slightly beneficial effect on yield efficiency, percent nut fill, and decreased nuts per kilogram. Several studies suggest that high root-zone temperature can cause heat injury to the roots and/or increase sensitivity of root tissues to other stresses. A study of maple (*Acer* sp.) suggested that heat injury to root tips may alter hormone relations and cause leaf epinasty (Wilkins et al., 1995). In Tromp's (1996) study on young apples, there was a definite temporal effect of high soil temperatures on shoot growth, suggesting that depending on the stage of fruit development, the tree may be more or less susceptible to root heat damage. It is possible that decreased temperature of the tree root-zones was a direct result of the shade provided by orchard floor vegetation and that this positively affected tree water status to the extent of increased harvest parameters. We did not measure soil temperature in our study, but the outer main effects we observed would be consistent with this mechanism because inner areas were already shaded by the tree and subject to less radiant heat.

Other possible considerations for the improved harvest parameters in plots with vegetation in the outer area could be soil condition (i.e., greater water infiltration, reduced compaction) or mulching effect of mowed vegetation. Further research is needed to fully understand the role of different types of vegetative groundcover, specifically non-weedy vegetation, on soil temperature and other factors in mature pecan orchards and how this affects pecan harvest over longer periods of time.

This study was unique in its focus on mature pecan trees and these findings suggest that there may be more benefits to maintaining orchard floor vegetation than were

Table 1. Nut yield and yield efficiency per tree[z] with P values shown in the lower portion of the table.

Treatment		Nut yield (kg/tree)			Yield efficiency (g·cm^{-1})		
Inner	Outer	2009	2010	Pooled 2009 and 2010	2009	2010	Pooled 2009 and 2010
Vegetated	Vegetated	62.9 ± 6.2	64.2 ± 5.8	64.2 ± 6.4	53.9 ± 4.1	48.7 ± 3.7	51.3 ± 3.6
Vegetation-free	Vegetated	66.4 ± 6.2	68.0 ± 5.8	68.3 ± 6.3	58.4 ± 4.1	56.6 ± 3.7	57.5 ± 3.6
Vegetation-free	Vegetation-free	58.9 ± 6.2	63.7 ± 5.8	62.3 ± 6.3	46.7 ± 4.1	44.8 ± 3.7	45.7 ± 3.6
Vegetated	Vegetation-free	63.1 ± 6.2	67.1 ± 5.8	66.1 ± 6.3	49.0 ± 4.1	45.1 ± 3.7	47.0 ± 3.6
Source							
P (vegetation inner)		0.9553	0.9721	0.9920	0.8009	0.3192	0.5166
P (vegetation outer)		0.5629	0.9097	0.7486	0.0666	0.0563	0.0483
P (inner × outer)		0.5507	0.5477	0.5431	0.4199	0.2839	0.3212
P (year)				0.2256			0.0381
P (inner × year)				0.9085			0.3328
P (outer × year)				0.5122			0.8504
P (inner × outer year)				0.9990			0.8046

[z] Yield and yield efficiency data are lsmeans ± SE.

Table 2. Percent kernel fill and number of nuts per kilogram weight[z] with P values shown in the lower portion of the table.

Treatment		Kernel fill (%)			Nuts per kilogram
Inner	Outer	2009	2010	Pooled 2009 and 2010	2010
Vegetated	Vegetated	55.8 ± 1.0	55.5 ± 0.5	55.6 ± 0.5	186.3 ± 3.7
Vegetation-free	Vegetated	54.3 ± 1.0	54.6 ± 0.5	54.2 ± 0.5	196.6 ± 3.7
Vegetation-free	Vegetation-free	53.8 ± 1.0	54.6 ± 0.5	54.4 ± 0.5	200.6 ± 3.7
Vegetated	Vegetation-free	54.1 ± 1.0	54.3 ± 0.5	54.2 ± 0.5	197.0 ± 3.7
Source					
P (vegetation inner)		0.3898	0.5899	0.2261	0.0849
P (vegetation outer)		0.2859	0.2479	0.0861	0.0701
P (inner × outer)		0.5725	0.2078	0.2060	0.3922
P (year)				0.6705	
P (inner × year)				0.6300	
P (outer × year)				0.6777	
P (inner × outer × year)				0.9705	

[z] Kernel fill and nut weight data are lsmeans ± SE.

previously recognized. Although the term "vegetative ground cover" is broad and does include weedy groundcover, weedy orchard floors pose a detriment in other ways (e.g., interference with harvest), and, as such, cover crops other than weeds are recommended.

Literature Cited

Atucha, A., I.A. Merwin, and M.G. Brown. 2011. Long-term effects of four groundcover management systems in an apple orchard. HortScience 46:1176–1183.

Elmore, C.L. 1989. Vegetation management systems in almond orchards. Calif. Agr. 43:16–17.

Faircloth, W.H., M.G. Patterson, W.G. Foshee, M.L. Nesbitt, and W.D. Goff. 2007. Comparison of preemergence and postemergence weed control systems in newly established pecans. Weed Technol. 21:972–976.

Folorunso, O.A., D.E. Rolston, T. Prichard, and D.T. Louie. 1992. Soil surface strength and infiltration-rate as affected by winter cover crops. Soil Technol. 5:189–197.

Foshee, W.G., W.D. Goff, M.G. Patterson, and D.M. Ball. 1995. Orchard floor crops reduce growth of young pecan trees. HortScience 30:979–980.

Glover, C.R. and R.D. Baker. 2000. Test your soil. New Mexico State University, Cooperative Extension Service Guide A-114. 21 Sept. 2011. <http://aces.nmsu.edu/pubs/_a/a-114.pdf>.

Goff, W.D., M.G. Patterson, and M.S. West. 1991. Orchard floor management practices influence elemental concentrations in young pecan trees. HortScience 26:1379–1381.

Herrera, E.E. 2000. Sampling pecan leaves for analysis. New Mexico State University Cooperative Extension Service Guide H-619. 21 Sept. 2011. <http://aces.nmsu.edu/pubs/_h/h-619.pdf>.

MacRae, R.J. and G.R. Mehuys. 1985. The effect of green manuring on the physical properties of temperate area soils. Adv. Soil Sci. 3:71–94.

Merwin, I.A. and J. Ray. 1997. Spatial and temporal factors in weed interference with newly planted apple trees. HortScience 32:633–637.

Miyamoto, S. 1983. Consumptive water use of irrigated pecans. J. Amer. Soc. Hort. Sci. 108: 676–681.

New Mexico State Climate Office. 2011. New Mexico State Climate Center. New Mexico State University, Las Cruces, NM. 10 June 2011. <http://weather.nmsu.edu/>.

NRCS Soil Survey, United States Department of Agriculture. 2010. Official Soil Series Descriptions. 4 May 2010. <http://soils.usda.gov/technical/classification/osd/ index.html>. USDA-NRCS, Lincoln, NE.

Patterson, M.G. and W.D. Goff. 1994. Effects of weed control and irrigation on pecan (*Carya illinoinensis*) growth and yield. Weed Technol. 8:717–719.

Patterson, M.G., W.D. Goff, N.R. McDaniel, L.M. Curtis, and T.W. Tyson. 1988. Total chemical weed control aids pecan tree growth. Highlights of Agr. Res. 35:3.

Patterson, M.G., G. White, and W.D. Goff. 1990. Effects of weed control and irrigation on the growth of young pecans. Weed Technol. 4:892–894.

Pritchard, T.L., W.K. Asai, and L.C. Hendricks. 1990. Orchard vegetation management: Effects on water use and soil characteristics. Western Pecan Growers Association Proc. p. 56–62.

Radosevich, S., J. Holt, and C. Ghersa. 2007. Ecology of weeds and invasive plants: Relationship to agriculture and natural resource management. 3rd Ed. Wiley-Interscience, Hoboken, NJ.

Ross, M.A. and C.A. Lembi. 2009. Applied weed science: Including the ecology and management of invasive plants. 3rd Ed. Prentice Hall, Upper Saddle River, NJ.

Sammis, T.W., J.G. Mexal, and D. Miller. 2004. Evapotranspiration of flood-irrigated pecans. Agr. Water Mgt. 69:179–190.

Sanchez, J.E., C.E. Edson, G.W. Bird, M.E. Whalon, T.C. Willson, R.R. Harwood, K. Kizilkaya, J.E. Nugent, W. Klein, A. Middleton, T.L. Loudon, D.R. Mutch, and J. Scrimger. 2003. Orchard floor and nitrogen management influences soil and water quality and tart cherry yields. J. Amer. Soc. Hort. Sci. 128:277–284.

Shackel, K.A., H. Ahmadi, W. Biasi, R. Buchner, D. Goldhamer, S. Gurusinghe, J. Hasey, D. Kester, B. Krueger, B. Lampinen, G. McGourty, W. Micke, E. Mitcham, B. Olson, K. Pelletrau, H. Philips, D. Ramos, L. Schwankl, S. Sibbett, R. Snyder, S. Southwick, M. Stevenson, M. Thorpe, S. Weinbaum, and J. Yeager. 1997. Plant water status as an index of irrigation need in deciduous fruit trees. HortTechnology 7:23–29.

Smith, M.W. 2011. Pecan production increased by larger vegetation-free area surrounding the tree. Sci. Hort. 130:211–213.

Smith, M.W., B.S. Cheary, and B.L. Carroll. 2002. Fescue sod suppresses young pecan tree growth. HortScience 37:1045–1048.

Smith, M.W., B.S. Cheary, and B.L. Carroll. 2005. Temporal weed interference with young pecan trees. HortScience 40:1723–1725.

Tromp, J. 1996. Sylleptic shoot formation in young apple trees exposed to various soil temperature and air humidity regimes in three successive periods of the growing season. Ann. Bot. (Lond.) 77:63–70.

Tworkoski, T.J. and D.M. Glenn. 2001. Yield, shoot and root growth, and physiological responses of mature peach trees to grass competition. HortScience 36:1214–1218.

USDA, National Agricultural Statistics Service. 2009. Noncitrus fruits and nuts. 7 Feb. 2010. <http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1113>.

Welker, W.V. and D.M. Glenn. 1991. Growth response of young peach trees to distribution pattern of vegetation-free area. HortScience 26:1141–1142.

Wilkins, L.C., W.R. Graves, and A.M. Townsend. 1995. Responses to high root-zone temperature among cultivars of red maple and freeman maple. J. Environ. Hort. 13:82–85.

Wright, G.C., W.B. McCloskey, and K.C. Taylor. 2003. Managing orchard floor vegetation in flood-irrigated citrus groves. HortTechnology 13:668–677.