SUNLIGHT AVAILABILITY AND NUT PRODUCTION AFTER THINNING OF PECAN TREES (*Carya illinoensis* K. Koch)

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ABSTRACT

The volume of a well-illuminated canopy is one of the main factors in the productivity of pecan trees. When mature pecan orchards with high densities (at least 100 trees per hectare) become overcrowded, photosynthetic active radiation penetration within the tree canopy and between trees, growth and nut production are adversely affected. Little research has been done to determine the effect of pecan tree thinning on available sunlight and productivity of the orchard. The objective of this experiment was to determine the effect of tree thinning on photosynthetic active radiation (PAR) available between and within permanent pecan trees, shoot growth, foliage density, nut production and nut quality. This study was carried out in a mature pecan orchard thinned at different stages from 25 to 50 % during the 1995-1997 period. Available PAR between and within pecan trees, shoot growth, foliage density and nut production per tree were affected by thinning treatments; however nut quality (kernel percentage) per tree during the three year period of the study was not significantly affected. The results of this study indicate that gradual orchard thinning at the appropriate time, in terms of orchard age, must be done to avoid drastic reduction in nut production.

ADDITIONAL KEY WORDS: tree thinning, sunlight penetration, shading, foliage density, production, kernel percentage.

DISPONIBILIDAD DE LUZ Y PRODUCCIÓN DE NUEZ DESPUÉS DEL ACLAREO DE ÁRBOLES DE NOGAL PECANERO (*Carya illinoensis* K. Koch)

RESUMEN

El volumen de la copa bien iluminada es uno de los principales factores en la productividad de árboles de árboles de nogal pecadero. Cuando las huertas adultas de nogal pecadero con altas densidades de plantación (al menos de 100 árboles por hectárea) presentan entrecruzamiento, la penetración de radiación fotosintéticamente activa dentro de la copa del árbol y entre árboles, el crecimiento y la producción de nuez son negativamente afectadas. La investigación fue realizada para estudiar el efecto del aclareo de árboles de nogal pecadero sobre la disponibilidad de la luz y productividad de la huerta es limitada. El objetivo del presente experimento fue determinar el efecto del aclareo de árboles sobre la disponibilidad de radiación fotosintéticamente activa (RFA) dentro y entre árboles permanentes, el crecimiento del brote, la densidad foliar, la producción y calidad de la nuez. Este estudio fue llevado a cabo en una huerta adulta de nogal pecadero con aclareo gradual de árboles de 25 a 50 %, durante el periodo 1995-1997. La disponibilidad de RFA dentro y entre árboles, la longitud de brotes, la densidad foliar y la producción por árbol fueron afectadas por los tratamientos de aclareo; sin embargo, la calidad de nuez (porcentaje de almendra) por árbol durante el periodo de tres años de estudio, no fue afectada significativamente. Los resultados de este estudio indican que un gradual aclareo de la huerta debe realizarse en el momento apropiado de edad de la misma, para evitar una drástica reducción en la producción de nuez.

PALABRAS CLAVE ADICIONALES: aclareo de árboles, penetración de luz, sombreo, densidad foliar, producción, porcentaje de almendra.

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INTRODUCTION

Mature pecan orchards require high sunlight levels for optimum growth, nut production, and quality. When tree canopies touch each other, bottom branches are overgrown by top branches and light penetration is reduced (Herrera,1996; Mc Eachern, 1996). Reduced light penetration will result in reduced growth and productivity, since only sun exposed terminals are potentially productive (Mc Eachern and Zajiceck, 1990). Low kernel percentage is also observed at low light penetration, followed by alternate bearing, and finally, by an indefinite period of limited growth (Herrera, 1994; Mc Eachern, 1996). In mature pecan orchards, when trees touch each other, only 20 % of the sunlight reaches the orchard floor (Halley and Malstrom, 1979). One of the major problems facing pecan growers, relative to overcrowding, is how to determine and maintain optimum tree spacing and canopy size. Goff (1992) considered orchards to be overcrowded when over 50 % of the orchard floor is shaded at noon. On the other hand, for leaves located in the canopy periphery, their photosynthetic light saturation is estimated to occur at 1,500 $\mu mol \cdot m^{-2} \cdot sec^{-1}$ or 75 % full sunlight (Andersen, 1994). Also, leaves exposed to 10 % of full sunlight which is common in the bottom part of the canopy, have CO_2 assimilation values near zero. The current shoot growth is proportional to growth gained during the previous season (Sparks, 1988). Also shoot growth is related to the amount of carbohydrates stored which is a function of leaf area per fruit and crop load (Sparks and Brack, 1981). In mature trees, longer shoots produce more leaf area (Sparks, 1969). The relationship of vigor to number of nuts demonstrates the importance of maintaining vigorous shoot growth. Moreover, the yield is related to percentage of fruiting shoots (Sparks, 1975), which in mature pecan trees is reduced in the lower position of the canopy due to reduced efficiency of the leaves resulting from mutual shading (Malstrom and Sparks, 1973). Fruiting shoots per tree are expected to vary inversely with tree density. Close spaces result in greater nut production per ground area until shading caused by crowding between trees increases to the point where orchard production declines (Smith, 1951; Romberg *et al*., 1959; Law *et al*., 1980; Worley, 1991).

In mature pecan orchards, when crowding occurs, some alternatives must be taken to correct it. Reduction in tree size by severe heading cuts or by removing selective limbs is one alternative (Wood, 1997). Removing trees in the properly time of orchard development is another; however detailed data on sunlight availability and some characteristics of shoot and tree productivity on thinned orchards are currently lacking. The purpose of this study was to determine PAR penetration, shoot growth, foliage density, and nut production and quality after tree removal in mature crowded pecan orchards.

MATERIALS AND METHODS

The survey was initiated in 1995 in an orchard located south of Las Cruces, New Mexico, USA. The site is located at an elevation of 1,475 m at latitude 34º 46" and longitude 106º 45". Average annual precipitation is 225 mm, about 70 % of the precipitation falls during April to October. Monthly average air temperature is 19 ºC, daily maximum summer temperatures average 32 ºC. Tree rows in the orchard were originally planted in 1962 on 9.15 m X 10 m spacing (122 trees per hectare). The soil in which these trees are growing is a Glendale clay loam (fine montmorillonitic, thermic Typic Torrent). The orchard is flood irrigated, well fertilized, and managed according to acceptable pecan orchard management practices. In this research, five thinning treatments of 0.5 ha each were studied: a) non-thinned trees, 122 trees per ha; b) a section thinned by 25 % in 1995, leaving 92 permanent trees per ha; c) a section thinned by 25 % in 1996; d) a section thinned by 25 % in 1997; and e) an orchard section thinned first to 25 % percent in 1996 and another 25 % in 1997, leaving 61 permanent trees per ha. Every other tree in every other row was cut in the 25 % thinning. For the 50% thinning treatment in 1997, the remaining trees in the thinned rows were removed resulting in 50 % of the original number of trees. Trees were cut down in January of each year.

Four trees were randomly selected in each section. Four PAR readings were taken at a 6 m height at 1.5, 3, 4.5 and 6 m from the outer perimeter of the trunk, toward the canopy periphery on each of the eight sides of the tree as follows: N,NE, E, SE, S, SW, W and NW. A 6 m long string line was used to locate each reading point. Readings were taken at noon, placing the string extreme in each mark made on the ground at 1.5 m intervals in each compass direction. A pruning tower was used to reach each canopy position. Each reading represented a percent of full sunlight derived after a similar reading was taken outside the canopy in full sunlight immediately after measuring sunlight within the tree canopy. In each orchard section, PAR was measured on the orchard floor below the tree canopy and on empty space between trees. Readings on the ground were taken in 18 X 30 m rectangles constructed with the longer sides parallel to the tree row direction each rectangle was divided into a grid of 540 equal sized squares of one square meter each. Measurements of PAR in the middle of each square meter were taken during full sunlight between 1,200 and 1,300 hours. Light percentage was calculated by averaging the 540 readings as a ratio of maximum unimpeded light and shaded areas for that time of day. Three 18 X 30 m rectangles were considered per each thinned section. Light inside the tree canopy and on the orchard floor was measured in late July in 1998 and 1999 using a line quantum sensor LI-191 SB (Li-COR, Inc. Lincoln NE). Readings of canopy foliage density (m^2 leaves m^{-3} tree canopy) were taken on three trees representing each thinning practice. An LAI-2000 Plant Canopy Analyzer (PCA) (LAI-2000 Li-COR, Inc. Lincoln, NE) was used to take canopy foliage density. An opaque mask restricting the field of view to 90° was snapped onto the sensor head to limit the view of the sensor to a quadrant of the tree. In August leaf density of each tree was estimated with four measurements with the PCA pointing in the four compass directions (N, S, E and W). The sensor was placed at the base of the tree. Leaf measurements were performed using the methodology suggested in the reading procedure for isolated trees with asymmetric canopy (Anonymous, 1992). Ten shoots located at 6-m height in the outer periphey from each of the eight canopy sides, were randomly selected from each tree in February 1997 and tagged for measuring annual shoot growth. Measurements were performed in December 1997, 1998 and 1999.

To determine the effect of tree removal on PAR within tree canopy, orchard floor, foliage density and shoot growth, data were analyzed per separated years, using an analysis of variance for a completely randomized experimental design. Mean separation between thinning treatments was done using an LSD test at a 5 % significance level.

Nut production from individual trees in each thinned section was evaluated in December each year. Pecan quality represented by kernel percentage (kernel weight X 100 divided by shell and kernel weight) was calculated from a randomly selected 40-pecan sample taken from each tree. Data for nut production and quality were analyzed using a completely randomized experimental design and means were separated using the LSD test.

RESULTS AND DISCUSSION

PAR within tree canopy

In 1998 orchard thinning increased PAR penetration inside the tree canopy particularly when 25 % thinning was carried out in 1996 and 50 % thinning was completed in 1997 (Table 1). When 25 % trees were removed in 1997 PAR percentage increased significantly in relation to non-thinning and 25 % thinning during 1995; however, it was similar to treatment where 25 % trees were removed in 1996. There was a reducing trend for PAR within the tree canopy in thinned sections as time of treatments increased. Lower PAR readings were expected to occur in the 1995 thinning because these trees had two-year cumulative growth periods after treatments, which caused an increment in the tree canopy growth.

On the other hand, the higher PAR levels found within the tree canopy in the orchard section thinned by 50 % in 1997, probably resulted from the increase in sunlight penetration due to orchard density reduction. Even thought pruning has a direct effect on light within the tree canopy, according to observations made by Worley (1991) and Wood, (1997); thinning the orchard also affects notably the increase of PAR within the tree canopy, which is critical at the bottom and close to the periphery of the canopy because overcrowding in adult orchards (Andersen, 1994). In 1999, the PAR penetration pattern inside the tree canopy was similar to that observed in 1998; however, a trend to low PAR readings inside the tree canopy were found in 1999 in for non-thinned and thinned trees due to the cumulative tree growth.

TABLE 1. Photosynthetic active radiation within tree canopies during a two-year period for five orchard thinning treatments.

Thinning treatments	PAR percentage 1998	PAR percentage 1999
Control	19.6 c^z	15.6 c
25 % thinned in 1995	22.6 c	18.0 c
25 % thinned in 1996	23.8 bc	18.9 bc
25 % tinned in 1997	27.8 b	23.8 b
50 % thinned in 1997	39.8 a	37.7 a

^{z}Means within columns with the same letter are equal according to LSD with a ($P \leq 0.05$).

PAR on the orchard floor

Orchard thinning treatments increased PAR penetration to the orchard floor (Table 2). In 1998 the control section (122 trees per ha) had the lowest PAR. The orchard section thinned by 25 % in 1995 (92 trees per ha) showed statistically similar PAR to those areas thinned to the same tree density in 1996 and 1997. However, a trend to found lower sunlight readings in 1995 was expected to occur because these trees had one and two-year cumulative growth after thinning, related to 1996 and 1997 treatments. The greatest PAR percentage on the ground was found in the lowest orchard density (61 trees per ha) after the number of trees was reduced by half.

For 1999 PAR penetration pattern to the orchard floor was similar to that observed in 1998. However, a trend to lower light readings striking the orchard floor during 1999 was found in both the nonthinned and the thinned trees, due probably to the cumulative tree growth and canopy expansion.

TABLE 2. Photosynthetic active radiation on the orchard floor during a two-year period for five orchard thinning treatments.

Thinning treatments	PAR percentage 1998	PAR percentage 1999
Control	17.4 c^z	13.7 c
25 % thinned in 1995	27.2 b	25.8 b
25 % thinned in 1996	31.7 b	26.0 b
25 % tinned in 1997	33.1 b	30.0 b
50 % thinned in 1997	56.2 a	46.2 a

^{z}Means within columns followed by the same letter are equal according to LSD with a ($P \leq 0.05$).

Shoot growth

In 1997, the highest shoot length was found in the orchard section thinned at 50 % in that year (Table 3), followed by 25 % tree removal during 1995 and 1996, which were not statistically different from each other, but greater than the thinning treatment carried out in 1997. The lowest shoot growth was found in the control trees. A similar pattern occurred in 1998 and 1999, in which a trend to reduce shoot length was found as years after tree removal increased. This gradually decreasing trend in shoot length, each year for the duration of the experiment, may have been due either to shading within tree canopy or shading caused by neighboring trees; which was expected to reduce leaf photosynthesis rate (Andersen, 1994; Malstrom and Sparks, 1973), and apical shoot growth due to lower carbohydrate production (Sparks, 1975; Sparks y Brack, 1981); thus generating cumulative effects on shoot growth for the next year, which follows the significant relationship found between the current season's growth with the observed length of one year-old branches (Sparks, 1988). The lowest apical shoot length found in the highest tree density (122 trees per ha) was probably due to overcrowding, confirming previous observations in mature orchards (McEachern and Zajiceck, 1990; Mc Eachern, 1996). Therefore, in crowded pecan orchards where thinning is not considered, canopy management for better sunlight penetration and greater shoot vigor might be something to consider (Herrera, 1996). Selective limb pruning is one practice that has direct impact on sunlight penetration inside the tree canopy and improves current season shoot growth and fruit set (Worley, 1991).

TABLE 3. Shoot growth during a three-year period for five orchard thinning treatments.

Thinning treatments	Shoot length (cm)		
	1997	1998	1999
Control	6.0 d[z]	5.3 d	4.2 d
25 % thinned in 1995	9.0 b	8.2 b	6.7 b
25 % thinned in 1996	8.7 b	8.1 b	6.6 b
25 % thinned in 1997	7.3 c	6.9 c	5.8 c
50 % thinned in 1997	10.2 a	9.7 a	9.2 a

[Z]Means within columns followed by the same letter are equal according to LSD with a ($P \leq 0.05$).

Foliage density

In 1997 tree canopy foliage density was similar in both thinned and non-thinned orchard sections (Table 4). In 1998, foliage density in non-thinned and orchard sections thinned by 25 % (92 trees per ha) were not statistically different from each other. However tree removal by 50 % (61 trees per ha) had the greatest foliage per canopy volume. Higher canopy foliage observed in the lowest orchard density, probably occurred as a result of better light conditions inside the tree canopy. In 1999, the foliage density pattern was similar to that observed in 1998; the greatest foliage density was found again in the treatment where 50 % tree removal occurred in 1997 leaving 61 trees per ha. This greater foliage per canopy volume resulted probably from a natural increment in growth due to three years of better PAR penetration. Foliage density patterns in thinned and non-thinned orchard sections were different from apical shoot length patterns through the 3-year period, because canopy foliage could have responded differently to environmental factors other than the shoots of the canopy periphery as was observed in apple trees (Fallahi *et al.*, 1994).

TABLE 4. Foliage density during a three-year period for five orchard thinning treatments.

Thinning treatments	Foliage density (m^2 leaves.m^{-3} canopy)		
	1997	1998	1999
Control	2.2 [NS]	2.2 b[z]	2.1 b
25 % thinned in 1995	2.2 [NS]	1.9 b	2.0 b
25 % thinned in 1996	2.1 [NS]	2.0 b	2.1 b
25 % thinned in 1997	2.0 [NS]	2.0 b	2.0 b
50 % thinned in 1997	2.0 [NS]	2.6 a	3.2 a

[Z]Means within columns followed by the same letter are equal according to LSD with a ($P \leq 0.05$).
[NS]Not significant according to LSD test ($P \leq 0.05$).

Nut production

Nut production on a per tree basis was significantly affected by tree removal during the three-year period of the study (Table 5). In 1997 nut production per tree in the treatment where 25 % thinning was carried out in 1996 and 50 % was completed in 1997, was statistically similar to treatments where 25 % thinning was carried out in 1995 and 1996, but greater than that of control trees and thinning by 25 % in 1997. Trees in thinned treatments showed the beneficial effects of the open spaces available for sunlight penetration on nut yield. This was likely due to sufficient vegetative growth to maintain shoot development and nut bearing (Sparks, 1969), and also from an increment in the bearing area resulting from an increase in sunlight exposure (Smith, 1951; Romberg *et al*., 1959) and photosynthesis (Andersen, 1994; Wood, 1997).

In 1998 the lowest nut production was observed in the orchard section thinned by 25 % in 1997 (92 trees per ha) and the non-thinned section (122 trees per ha). These yields were statistically different from that found in the orchard section thinned by 25 % in 1995 and 1996; yields for these latter treatments were similar to the yield from the section thinned by 50 % in 1997. In this season, alternate bearing was present in thinned and non-thinned sections, even thought the trend for irregular production between seasons was greater in thinned treatments; probably because PAR increment enhanced apical shoot growth. It has been found that the longer the shoot, the more pistillate flowers that are borne on a shoot (Sparks, 1975). However, the rate of carbohydrate storage would be expected to diminish, reducing the shoot growth potential as well as the number of female blossoms the following spring. In non-thinned trees, this exhaustive process was probably lower, resulting in reduced alternate bearing. In 1999, the lowest nut production was found in the control (122 trees per ha), followed by orchard thinning by 25 % in 1996 and 1997 treatments, which were similar to the 25 % tree removal treatment carried out in 1995, but statistically lower than the orchard being thinned by 50 % in 1997. It was expected that the trend to increase nut yield, would compensate for the fewer trees per hectare in thinned plots. This was not found over the three-year study period.

In order to avoid adversely affecting nut production, crowded mature pecan orchards cannot be thinned in a given winter. Instead, partial pruning of temporary trees, or a gradual thinning by eliminating 25 % of the trees or less every year (or every other year depending of the extent of the shading), should be done (Herrera, 1994). This gradual removal will soften the sudden decrease in yields that occurs when 50 % of tree removal is carried out.

After thinning the orchard, canopy management in permanent trees through selective limb pruning (Worley, 1991) or mechanical hedge pruning (McEarchern, 1996) must follow. This process, which has a direct impact on bettering sunlight within the tree canopy, may be expected to increase photosynthesis rate in formerly shaded areas.

TABLE 5. Nut production per tree during a 3-year period for five orchard thinning treatments.

Thinning treatments	Nut production (kg)		
	1997	1998	1999
Control	26.8 c[z]	20.0 b	29.7 c
25% thinned in 1995	39.5 ab	27.3 a	50.8 ab
25% thinned in 1996	42.8 ab	26.2 a	41.7 b
25% thinned in 1997	34.3 b	15.5 b	45.9 b
50% thinned in 1997	46.6 a	25.4 a	58.3 a

[z]Means within columns followed by the same letter are equal according to LSD with a ($P \leq 0.05$).

Nut quality

Nut quality expressed in kernel percentage was not affected significantly by orchard thinning. Nut quality appeared to be a function of the amount of nuts on the tree. In 1997 and 1999, which were years of heavy nut crops in the orchard, a decreasing trend in nut quality was observed. In 1997 a similar nut quality was observed (54 % of kernel) for both, thinned and non-thinned treatments. In1998, a low nut production year, we observed an increasing trend for kernel percentage. Orchard sections thinned by 25 % in 1995 and 1996, showed a nut production with 55 % of kernel; this production increased to 56 % in thinned treatments by 25 % or 50 % in 1997. In 1999 kernel percentage was 54 in thinned treatments. A different pattern in kernel percentage was observed in control trees (54, 54 and 53) for 1997, 1998 and 1999, respectively. Patterns of nut quality decrements, particularly in 1999, may have been due to cumulative shading.

CONCLUSIONS

Results during the three years of this study indicate that PAR inside the tree canopy and on the orchard floor were affected by thinning treatments. PAR increased as orchard density decreased. Orchard thinning treatments also affected shoot growth and foliage density, which were greater as the tree removal gradient increased, resulting in better light conditions for PAR. Nut production was affected by thinning during the three years of the study. A low production was observed after a high production year, that was better appreciated in the thinning treatments, especially in the plot where the number of trees was reduced by half. Tree removal did not have a significant effect on nut quality.

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