Growth and Nitrogen Status of Young Pecan Trees Using Fertigation

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***Abstract*. The prolonged period from tree planting to first commercial harvest of pecan [*Carya illinoinensis* (Wangenh.) K. Koch] provides incentive for many growers to intensively manage young trees to induce commercial production as soon as possible. This management includes high nitrogen (N) application rates with or without fertigation. However, there remains little data regarding the effect of N fertilization or fertigation on young pecan trees grown under southeastern U.S. orchard conditions. The objectives of this study were to compare the effects of fertigation with more commonly recommended forms of fertilization on growth and leaf N, phosphorous (P), potassium (K), and zinc (Zn) concentrations of first- through third-leaf pecan trees irrigated with microsprinklers. An optimal growth rate of young pecan trees was obtained as easily with a balanced granular fertilizer application using significantly less N compared with fertigation applications. The minimal treatment differences observed along with the fact that leaf N concentration never fell below the minimum recommended level in any treatment throughout the study supports the supposition that first-year pecan trees require no N fertilizer during the year of establishment. Only modest N application rates are required during the second and third growing seasons. This practice helps to promote optimal tree growth while minimizing excessive losses of N to the environment.**

The recent export-driven increases in pecan price have renewed interest in the crop and led to the planting of additional pecan acreage throughout the U.S. pecan belt (USDA, 2012; Wells, 2014). A survey of pecan producers throughout Georgia documented the planting of 391,488 pecan trees and 15,328 additional pecan acres since 2010. The majority of these new pecan plantings are equipped with microsprinkler or drip irrigation systems equipped for fertigation (Wells, 2014).

Cultural practices that promote tree growth and vigor during the establishment phase are desirable for increasing tree fruiting surface. Irrigation and N fertilizer must be managed appropriately to achieve optimum tree growth and nut production, while ensuring minimal environmental impact. Historically, N fertilizer recommendations for young pecan trees in Georgia orchards have been minimal regarding the use of dry, granular fertilizer. Fertigation was discouraged because of the perceived potential for root damage from excessive concentration of N in the root zone (Wells, 2007). The prolonged period from tree planting to first commercial harvest of pecan provides incentive for many growers to intensively manage young trees to induce commercial production as soon as possible. This management includes high N application rates with or without fertigation. However, there remains very little data regarding the effect of N fertilization or fertigation on young pecan trees grown under southeastern U.S. orchard conditions.

Worley (1991) suggested that application of fertilizer to the backfill soil at transplanting did not affect caliper, height, or vigor of pecan trees. Photosynthesis and growth increased with N supply but was dependent upon leaf N:sulfur (S) ratio in a greenhouse study of pecan seedlings (Hu and Sparks, 1992). Conner (2007) found pecan nursery seedling height and caliper were unaffected by N fertigation except for the N rate of 40 g per tree, which suppressed seedling growth and that N needs of the seedlings were met by a preplant application of 50 lb/acre N applied as 10N–4.4P–8.3K.

Fertilizer N applied in excess of that needed to support optimum productivity accumulates in the soil and becomes increasingly vulnerable to a variety of loss mechanisms including leaching and denitrification. Excessive application of fertilizer N in orchards occurs when growers have a limited awareness of tree N use, soil N availability, tree N status, and the relationship between tree N status and tree capacity for N uptake (Weinbaum et al., 1992). Pecan trees in the first 2–3 years of establishment have a limited root system compared with more mature trees, thus their capacity for uptake of N and other nutrients is limited. In addition, most pecan nurseries maintain high fertility to shorten rotation time and increase nursery production (Conner, 2007). As a result, trees often maintain adequate levels of N through the first year following transplant to the orchard. The lack of proper soil moisture management and the nonresponsiveness of trees to excessive N fertilization are integrally related to N pollution of the environment (Weinbaum et al., 1992). The perception that annual applications of significant amounts of fertilizer N represent cheap insurance against the economic risks associated with insufficient N availability is common among growers.

Additional research is needed in the southeastern United States to evaluate the effects of fertigation on microsprinkler-irrigated young pecan trees compared with other forms of fertilization. The objectives of this study were to compare the effects of fertigation with more commonly recommended forms of fertilization on growth and N status of first- through third-leaf young pecan trees under microsprinkler irrigation.

Materials and Methods

Study site, experimental design, and sampling

Two experiments were conducted from 2013 to 2014 in a commercial pecan orchard located in Pulaski County, GA. The orchard was located at 31°20′ N latitude and –83°37′ W longitude. All trees were irrigated with microsprinklers at a rate of 56.8 $L \cdot h^{-1}$. Microsprinklers were placed ≈0.3 m from the tree trunk. Trees were irrigated 4–6 h every other day in the absence of rain from April to September. Trunks were protected with corrugated tree guards (A.M. Leonard, Piqua, OH). The orchard was managed under commercial conditions according to University of Georgia Cooperative Extension recommendations (Hudson et al., 2012). A 3.7-m-wide vegetation-free strip was maintained with the herbicide glyphosate along the tree row in all plots. Row middles consisted of bermudagrass (*Cynodon dactylon* L.) sod.

Experiment 1. Bare-root ‘Cunard’ pecan trees grafted to ‘Elliott’ rootstock were planted from nursery stock. Trees were planted in Jan. 2013 at a spacing of 9 m × 15.2 m on Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudult). The following treatments were evaluated: 1) fertigation using liquid urea ammonium nitrate (UAN) (28N–0P–0K) with 5% S at a total volume of 68 L UAN/ha applied to deliver a rate of 27.6 kg N/ha; 2) granular urea (46N–0P–0K) at a rate of 27.6 kg N/ha; 3) dry, balanced fertilizer (10N–10P–10K) applied at a rate of 3.25 kg N/ha; and 4) nontreated control. The fertigation rate above was chosen to mimic practices currently used by some pecan producers in Georgia. Treatments were arranged in a randomized complete block design with three blocks and each treatment represented once per block. Individual plots consisted of 10 adjacent trees within a single orchard row. Measurements were taken from each tree within each plot. Individual plots received the same treatments in consecutive years.

Liquid UAN was applied through the irrigation system using a Dosatron Dosacart fertilizer injector (Dosatron Products, Sunnyvale, FL). Balanced granular fertilizer and granular urea were applied in a 2.32 m^2 area around individual trees. Balanced granular fertilizer

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was applied once per year (9 May) in 2013 and twice per year (25 Apr. and 29 June) in 2014. The total volumes of UAN and granular urea were each split into four equal applications of 6.9 kg N/ha on 9 May, 28 June, 12 July, and 6 Aug. 2013. During 2014, applications were made on 25 April, 28 May, 29 June, and 29 July. Phosphorus (P) and Potassium (K) were applied to all treatments through the irrigation system as a 1N–6P–13K liquid solution at a volume of 48 L·ha^{-1} to deliver 8.4 kg P/ha and 18 kg K/ha. Application dates were 8 May 2013 and 25 Apr. 2014. Zinc was applied as zinc sulfate to all treatments through the irrigation system in a 16N–0P–0K–20Zn liquid solution at a volume of 4.7 L·ha^{-1} to deliver 1.12 kg Zn/ha. Application dates were 8 May 2013 and 25 Apr. 2014. Trees were irrigated for ≈1 h following fertilizer injections to flush fertilizer from the irrigation system.

Stem diameter at 76.2 cm above the soil surface was measured on 9 May 2013, 13 July 2013, 8 Aug. 2013, 10 Sept. 2013, 22 Oct. 2013, 21 Apr. 2014, 27 May 2014, 18 June 2014, 28 July 2014, and 16 Sept. 2014. Foliage was sampled in late July each year by collecting one leaflet pair from 20 compound leaves per tree. All leaflet samples were taken from the middle leaf of sun-exposed terminals. Leaflet samples were washed in a dilute phosphate-free detergent solution (0.1% detergent) followed by rinsing with deionized water. Leaves were then dried to a constant weight at 65 °C and ground in a Wiley Mill (Wiley, Philadelphia, PA) to pass a 1-mm screen. Leaves for nutrient analysis were ground with a mortar and pestle. Samples were analyzed for N by combustion using a Leco FP528 protein/N determinator (Leco Corp., St. Joseph, MI). Samples were analyzed for K, P, and Zn by an inductive coupled plasma spectrophotometer (ICP) coupled to a Digiblock 3000 (SCP Science, Baie D'Urfé, Quebec, Canada).

Experiment 2. Bare-root 'Cape Fear' pecan trees grafted to 'Elliott' rootstock were planted from nursery stock. Trees were planted in Jan. 2012 at a spacing of 9 m × 15.24 m on Red Bay sandy loam (fine-loamy, kaolinitic, thermic Rhodic Kandiudults). All trees received one application of dry, balanced fertilizer (10N–10P–10K) at a rate of 3.25 kg·ha^{-1} in June 2012. Beginning in 2013, the following treatments were evaluated: 1) fertigation using liquid UAN (28N–0P–0K) with 5% S at a total volume of 136 L UAN/ha applied to deliver a rate of 55.2 kg N/ha; 2) fertigation using liquid UAN (28N–0P–0K) with 5% S at a total volume of 68 L UAN/ha applied to deliver a rate of 27.6 kg N/ha; 3) granular urea (46N–0P–0K) at a rate of 27.6 kg N/ha; 4) dry, balanced fertilizer (10N–10P–10K) applied at a rate of 9.75 kg·ha^{-1}; 5) nontreated control. Treatments were arranged in a randomized complete block design with three blocks and each treatment represented once per block. Individual plots consisted of 10 adjacent trees within a single orchard row. Measurements were taken from each tree within each plot. Individual plots received the same treatments in consecutive years.

Liquid UAN was applied through the irrigation system using a Dosatron Dosacart fertilizer injector (Dosatron Products). Balanced granular fertilizer applications were split into three applications per year (9 May, 28 June, and 12 July) in 2013 and three applications per year (21 Apr., 27 May, and 18 June) in 2014. The total volumes of UAN and granular urea were each split into four separate applications. The high fertigation rate received 13.8 kg N/ha in each application. The low fertigation and granular urea treatments each received 6.9 kg N/ha per application. Treatment dates were 9 May, 28 June, 12 July, and 6 Aug. 2013. During 2014, applications were made in 25 Apr., 28 May, 29 June, and 29 July. Phosphorus and K were applied to all treatments through the irrigation system as a 1N–6P–13K liquid solution at a volume of 48 L·ha^{-1} to deliver 8.4 kg P/ha and 18 kg K/ha. Application dates were 23 Apr. 2013 and 25 Apr. 2014. Zinc was applied as zinc sulfate to all treatments through the irrigation system as a 16N–0P–0K–20Zn liquid solution at a volume of 4.7 L·ha^{-1} to deliver 1.12 kg Zn/ha. Application dates were 8 May 2013 and 25 Apr. 2014. Trees were irrigated for ≈1 h following fertilizer injections to flush fertilizer from the irrigation system.

Trunk diameter at 76.2 cm above the soil surface was measured on 23 Apr. 2013 and again at each of the following dates: 13 July 2013, 8 Aug. 2013, 10 Sept. 2013, 22 Oct. 2013, 21 Apr. 2014, 27 May 2014, 18 June 2014, 28 July 2014, and 16 Sept. 2014. Foliage sampling and leaflet nutrient analysis were the same as those described for Experiment 1.

Statistical analyses of data were performed with SAS (SAS Institute, Cary, NC). Analysis of variance (ANOVA) was used to compare treatment effects. Repeated measures ANOVA was used to compare differences between years. Means were separated using Tukey's honestly significant difference test ($P \leq 0.05$).

Results and Discussion

Young pecan trees require excellent cultural management to maximize growth and development. Practices that promote growth of pecan transplants include irrigation, transplanting early in the dormant season (Wood, 1996), and weed control (Smith et al., 2000). Historically, N fertilizer has not been considered a major factor in early growth of pecan trees following transplant in the orchard (Wells, 2007).

Leaf tissue N concentration in fertilized and unfertilized trees was above the standard minimum recommended concentration for pecan of 2.5% (Smith et al., 2012; Wells, 2007, 2009) in all treatments of both cultivars throughout the study (Tables 1 and 2). Leaf N was numerically higher for treated and control trees of both cultivars in 2014 than in 2013; however, there were no statistically significant differences.

During the first year of study, 'Cunard' pecan tree leaf N concentration did not respond to fertilizer treatment (Table 1). Both fertigation treatments and the balanced granular fertilizer treatment had higher leaf N concentrations than the granular urea and control treatments in second-year 'Cape Fear' trees during 2013 (Table 2). Control trees received a small amount of N (1.5 kg N/ha) with the application of P, K, and Zn; however, this amount was considered negligible. Leaf P concentration was higher in both fertigation treatments for second-year 'Cape Fear' trees compared with the remaining treatments (Table 2). Leaf K concentration was higher in the low-rate fertigation treatment than in the high-rate fertigation and granular urea treatments for second-year 'Cape Fear' trees as well (Table 2). Leaf Zn concentration was also higher in the low-rate fertigation treatment than in the balanced granular fertilizer treatment for second-year 'Cape Fear' trees. Leaf Zn was below the minimum recommended sufficiency level of 50 ppm (Smith et al., 2012) for 'Cape Fear' in 2013, but leaf Zn concentration in all treatments was within the recommended sufficiency range in 2014 (Table 2).

During year 2 of the study, leaf N concentration of second-year 'Cunard' trees was higher in the balanced granular fertilizer and granular urea treatments than in the control treatment, but no difference was observed between the fertigation treatment and all other treatments (Table 1). Leaf N concentration of third-year 'Cape Fear' trees was

Table 1. Mean leaf nitrogen (N), leaf phosphorus (P), leaf potassium (K), and leaf zinc (Zn) concentrations of 'Cunard' pecan trees receiving fertigation, balanced granular fertilizer, granulated urea, and control treatments during the first (2013) and second (2014) growing seasons following transplant.

		Leaf nutrient concn			
Yr	Treatment	N (%)	P (%)	K (%)	Zn (ppm)
2013					
	UAN[y] fertigation (27.6 kg N/ha)	2.63 a[z]	0.13 a	0.99 a	69 a
	Balanced granular fertilizer (3.25 kg N/ha)	2.61 a	0.14 a	1.13 a	51 a
	Granular urea (27.6 kg N/ha)	2.76 a	0.12 a	1.06 a	92 a
	Nontreated control	2.63 a	0.16 a	1.14 a	48 a
2014					
	UAN[y] fertigation (27.6 kg N/ha)	2.88 ab	0.13 ab	1.05 a	58 a
	Balanced granular fertilizer (6.5 kg N/ha)	3.14 a	0.14 a	1.30 a	66 a
	Granular urea (27.6 kg N/ha)	3.07 a	0.11 b	1.09 a	52 a
	Nontreated control	2.70 b	0.12 ab	1.08 a	61 a

[z]Means followed by the same letter within each year are not different at $P < 0.05$ by Tukey's honestly significant difference test.

[y]UAN = urea ammonium nitrate.

higher in the low-rate fertigation treatment than in the granular urea treatment, but no other differences were observed (Table 2). High soil water content and temperatures above 21 °C at the time of urea application can increase denitrification losses and volatilization can occur with increasing temperatures if urea is not incorporated into soil by irrigation (Havlin et al., 2005). Soil moisture was not excessive at any point in the study during the time of urea application and urea was incorporated with irrigation, though temperatures ranged from 28 to 35 °C when urea was applied. Therefore, losses of N to the environment in the granular urea treatment should not have been excessive compared with the remaining treatments. Leaf P concentration was higher in the balanced granular fertilizer treatment than in the granular urea treatment for ‘Cunard’ trees in year 2 (Table 1). All treatments, with the exception of the balanced granular fertilizer treatment resulted in leaf P concentrations below the minimum sufficiency range of 0.14% recommended by Smith et al. (2012). Leaf Zn concentration was higher for granular urea and the control treatments than for the low fertigation rate for ‘Cape Fear’ in year 2 of the study (Table 2).

Trunk diameter growth is related to tree canopy growth and can also reflect response to fertilizer N (Castle et al., 1994). Trunk diameter of both cultivars increased in all treatments throughout both growing seasons, with very little growth occurring in first-year ‘Cunard’ trees compared with the following year (Figs. 1 and 2). Root dry weight typically comprises 55%–70% of total tree dry weight 1 year after transplant (Wells, 2010), which may suggest that pecan tree transplants direct most of their resources to root establishment in the first growing season in the orchard. There were no treatment differences in trunk diameter growth for ‘Cunard’ pecan trees in the first or second years following transplant (Table 3). Trunk diameter growth of second-year ‘Cape Fear’ trees was greater in the low-rate fertigation treatment than in the granular urea treatment in 2013; however, no other treatment differences were observed (Table 4). During the final year of study, no treatment differences were observed for third-year ‘Cape Fear’ trunk diameter.

Lack of pecan tree response to fertilizer N during the year of planting, as observed for first-year ‘Cunard’ trees, supports previous recommendations for pecan (Wells, 2007) that no fertilizer N or only a modest amount of fertilizer N is necessary for pecan trees during the first growing season in the orchard. Similarly, application of fertilizer N in the second and third years following planting had minimal effects on growth or leaf N. Even when differences in leaf N were observed, concentrations were within the recommended sufficiency range. Thus, only a modest amount of fertilizer N is needed in second and third year trees to maintain adequate pecan tree growth and leaf N concentration.

Lack of young fruit tree response to N has been attributed to mineralized soil organic N, low weed competition, residual soil inorganic N, low tree N requirements, and remobilization of stored N from fertilizer applied in the nursery (Boman, 1993; Castle and Rouse, 1990; Swietlik, 1992; Weinert et al., 2002). Although no direct measurements of soil N were taken during this study, the soils on which the study was conducted generally retain very little plant available N, and fertilizer N is usually required for optimal plant growth. Therefore, it is likely that tree N reserves were remobilized for growth of first-leaf pecan trees.

Fertigation is an effective method of applying fertilizer to pecan trees, especially in large orchards, where additional hand labor may be required for manual application of dry fertilizer to each tree. Fertigation at rates up to 27.6 kg N/ha for first-year trees and 55.2 kg N/ha for second- and third-year trees can be safely applied; however, such rates are apparently unnecessary for adequate growth and development of young pecan trees and may result in nutrient leaching and runoff. Fertigation of young pecan trees at the above rates only seem to be a cause for concern regarding root damage during the establishment phase if irrigation systems are not properly maintained or flushed following fertilizer application, allowing excessive N accumulation in the root zone of young trees.

Although there was not a consistent response of leaf P or leaf K concentration to balanced fertilizer, the trees did appear to

Table 2. Mean leaf nitrogen (N), leaf phosphorus (P), leaf potassium (K), and leaf zinc (Zn) concentrations of ‘Cape Fear’ pecan trees receiving fertigation (high rate), fertigation (low rate), balanced granular fertilizer, granulated urea, and control treatments during the second (2013) and third (2014) growing seasons following transplant.

		Leaf nutrient concn			
Yr	Treatment	N (%)	P (%)	K (%)	Zn (ppm)
2013					
	UAN[y] fertigation (55.2 kg N/ha)	2.72 a[z]	0.13 a	1.20 b	32.5 ab
	UAN[y] fertigation (27.6 kg N/ha)	2.74 a	0.14 a	1.30 a	43.5 a
	Balanced granular fertilizer (9.75 kg N/ha)	2.72 a	0.11 b	1.23 ab	21.5 b
	Granular urea (27.6 kg N/ha)	2.56 b	0.11 b	1.04 c	30.0 ab
	Nontreated control	2.50 b	0.11 b	1.08 bc	38.5 ab
2014					
	UAN[y] fertigation (55.2 kg N/ha)	2.90 ab	0.12 a	1.18 a	74.3 ab
	UAN[y] fertigation (27.6 kg N/ha)	3.17 a	0.12 a	1.11 a	55.7 b
	Balanced granular fertilizer (9.75 kg N/ha)	2.86 ab	0.11 a	0.99 a	78.2 ab
	Granular urea (27.6 kg N/ha)	2.84 b	0.10 a	0.99 a	94.2 a
	Nontreated control	2.91 ab	0.11 a	1.03 a	100 a

[z]Means followed by the same letter within each year are not different at $P \leq 0.05$ by Tukey’s honestly significant difference test.
[y]UAN = urea ammonium nitrate.

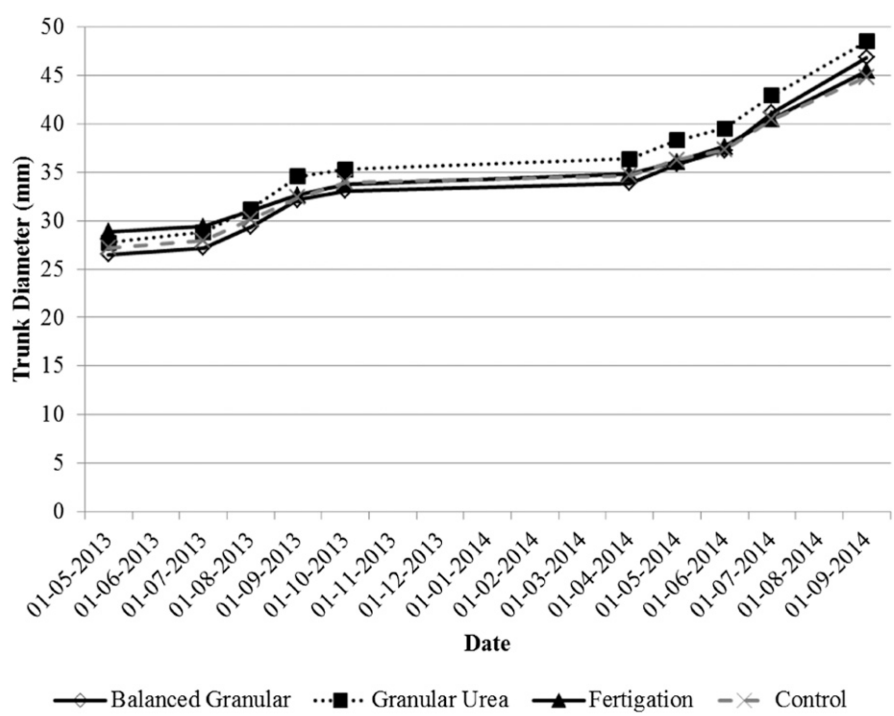

Fig. 1. Mean trunk diameter growth of ‘Cunard’ pecan trees during the first (2013) and second (2014) growing seasons following transplant. Treatments were fertigation, balanced granular fertilizer, granulated urea, and control.

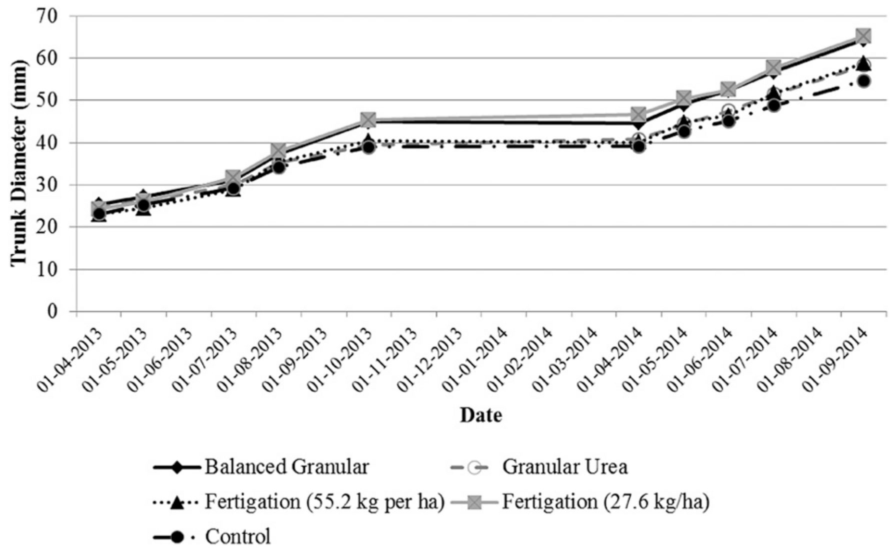

Fig. 2. Mean trunk diameter growth of 'Cape Fear' pecan trees during the second (2013) and third (2014) growing seasons following transplant. Treatments were fertigation (high rate), fertigation (low rate), balanced granular fertilizer, granulated urea, and control.

Table 3. Mean trunk diameter growth and mean trunk diameter growth per kilogram nitrogen (N) applied per hectare for 'Cunard' pecan trees as affected by fertigation, balanced granular fertilizer, granulated urea, and control treatments during the first (2013) and second (2014) growing seasons following transplant.

Yr	Treatment	Trunk diam growth (mm)	Trunk diam growth per (mm)
2013			
	UAN[y] fertigation (27.6 kg N/ha)	5.4 a[z]	0.20 b
	Balanced granular fertilizer (3.25 kg N/ha)	6.5 a	2.0 a
	Granular urea (27.6 kg N/ha)	7.6 a	0.28 b
	Nontreated control	6.7 a	—
2014			
	UAN[y] fertigation (27.6 kg N/ha)	11.0 a	0.39 b
	Balanced granular fertilizer (6.5 kg N/ha)	12.9 a	1.98 a
	Granular urea (27.6 kg N/ha)	12.1 a	0.44 b
	Nontreated control	10.1 a	—

[z]Means followed by the same letter within each year are not different at $P \leq 0.05$ by Tukey's honestly significant difference test.
[y]UAN = urea ammonium nitrate.

Table 4. Mean trunk diameter growth mean trunk diameter growth per kilogram nitrogen (N) applied per hectare for 'Cape Fear' pecan trees as affected by fertigation (high rate), fertigation (low rate), balanced granular fertilizer, granulated urea, and control treatments during the second (2013) and third (2014) growing seasons following transplant.

Yr	Treatment	Trunk diam growth (mm)	Trunk diam growth per kg N/ha (mm)
2013			
	UAN[y] fertigation (55.2 kg N/ha)	17.4 ab[z]	0.32 c
	UAN[y] fertigation (27.6 kg N/ha)	21.1 a	0.76 b
	Balanced granular fertilizer (9.75 kg N/ha)	19.7 ab	2.0 a
	Granular urea (27.6 kg N/ha)	14.8 b	0.54 bc
	Nontreated control	16.2 ab	—
2014			
	UAN[y] fertigation (55.2 kg N/ha)	18.8 a	0.34 c
	UAN[y] fertigation (27.6 kg N/ha)	18.6 a	0.67 b
	Balanced granular fertilizer (9.75 kg N/ha)	19.8 a	2.0 a
	Granular urea (27.6 kg N/ha)	17.5 a	0.63 b
	Nontreated control	15.5 a	—

[z]Means followed by the same letter within each year are not different at $P \leq 0.05$ by Tukey's honestly significant difference test.
[y]UAN = urea ammonium nitrate.

respond to the balanced fertilizer treatment. This result was likely associated with applying less N to obtain the same growth rate. Although there were minimal or no differences in trunk diameter growth between treatments, there were significant differences in trunk diameter growth per unit of N applied (Tables 3 and 4). The balanced granular fertilizer treatment consistently resulted in differences in trunk diameter growth per unit N applied ranging from 163% to 900% over that of other fertilization methods (Table 3 and 4). Actual N rates for balanced granular fertilizer were between 76% and 82% lower than that of the fertigation and granular urea treatments, suggesting such excessive applications are unwarranted, inefficient in regard to growth per unit of N applied, and may lead to excessive leaching of fertilizer N into groundwater and streams. This further emphasizes the positive benefits of minimal application of fertilizer N to young pecan trees. However, the scope of this study does not address the possibility that high N rates applied early in the life of the orchard may affect tree precocity and the profitability of young pecan orchards within the first few years of bearing. These parameters should be evaluated in further studies.

In summary, an optimal growth rate of young pecan trees can be obtained as easily with a balanced granular fertilizer application using significantly less N compared with fertigation applications. The minimal treatment differences observed along with the fact that leaf N concentration never fell below the minimum recommended level in any treatment throughout the study, further supports the supposition that first-year pecan trees require no N fertilizer during the year of establishment. Only modest N application rates are required during the second and third growing seasons. This practice helps to promote optimal tree growth while minimizing excessive losses of N to the environment (Weinbaum et al., 1992).

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