

# Long-term Performance of Pecan Trees when Nitrogen Application is Based on Prescribed Threshold Concentrations in Leaf Tissue

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**Abstract.** A threshold of 2.75% N was most practical for the low end of the sufficiency range when lower thresholds of 2.25%, 2.50%, 2.75%, and 3.00% were tested on old 'Stuart' pecan [*Carya illinoensis* (Wangenh.) C. Koch] trees. Application of 224 kg N/ha annually reduced nut size when compared with application of 112 kg/ha made only when leaf N dropped below 2.25%, 2.50%, 2.75%, or 3.00%. Yield and tree growth were similar when 112 kg·ha<sup>-1</sup> was applied only when leaf N dropped below 2.75% and when 224 kg·ha<sup>-1</sup> was applied annually. No N application was necessary to meet the 2.75% threshold for 3 of the 16 years.

Several studies have assessed various rates of N applied to pecan trees (Hunter and Hammar, 1947; Skinner, 1922; Smith et al., 1985; Sparks, 1968; Storey et al., 1986; Worley 1974). Usually, leaf N increases with an increase in application rate, but not necessarily in proportion to the application rate. The increase in leaf N from additional increments of high N rates is often insignificant (Worley, 1974).

Leaf analysis standards are established for the major pecan growing regions, and if leaf elemental concentrations fall within a specified sufficiency range for an element, applications of that element are not recommended. The sufficiency range for Georgia, originally set for leaf N in 1965, was 2.00% to 2.90% (Worley, 1966), but was changed to 2.50% to 2.90% in 1968 (Worley, 1971) as more information became available. The current sufficiency range, set by the Georgia Cooperative Extension Service for N in pecan, is 2.50% to 3.30%; however, applications are recommended if leaf N concentrations are <3.00% (Plank, 1988).

Greenhouse nutrition studies in sand culture on first-year pecan seedlings indicated that leaf N between 2.6% and 2.9% was optimum for tree growth (Sparks, 1968). In field studies, growth and yield continued to increase as leaf N increased to a maximum of 2.670 (Sparks, 1968); however, samples taken in commercial orchards frequently exceed 3.00% N, thus indicating luxury consumption.

Responses to N vary with location. In Oklahoma, highest yields were obtained from the first 56 kg N/ha increment, but leaf N continued to increase as applications increased through 224 kg·ha<sup>-1</sup> (Smith et al., 1985). The maximum leaf N concentration reached in these studies was 2.39%, and the authors suggested a lower threshold limit of 2.25% for the sufficiency range.

Excess N can also be a problem. In Texas, applications of 436 kg N/ha reduced yield by 80%, doubled the amount of sticktights (nuts with unopened shucks), and reduced nut size compared with applications of 109 or 218 kg N/ha (Storey et al., 1986). Leaf N concentration was not reported.

Concentrations of N can remain fairly constant for several years in pecan foliage if trees have been well-fertilized (Worley et al., 1974). It took 6 years for leaf N concentrations to reflect

different fertilizer application rates in this study. Apparently, N may accumulate in storage organs or recycle when leaves fall to the ground and decay (Adams and Attiwill, 1986). The concentration of N in the leaves illustrates the tree's N nutritional status; thus, it appears practical to apply N only when leaf N drops below the sufficiency threshold. The purpose of this study was to test the effects of N applications only when leaf concentrations drop below specified thresholds and to determine the optimum leaf N concentration for the lower threshold of the sufficiency range. The criteria measured were yield, nut quality, tree growth, and leaf and soil elemental concentrations.

## Materials and Methods

Mature (> 50-year-old) 'Stuart' pecan trees spaced 21 x 21 m and growing on a Tifton loamy sand (Ultisol Plinthic Paleodults: fine loamy silicious, thermic) near Tifton, Ga. were used. The trees had been used previously for a fertilizer study (Worley, 1974; Worley et al., 1974) and were healthy and productive. Treatments were randomized over the orchard without regard for the previous study. The current study covered the period from 1973 through 1988. A long-term study was necessary for residual N to dissipate in the low-N threshold treatments, to permit measurement of the effect of infrequent N applications, and to overcome annual variation due to alternate bearing. Leaf concentration of elements was determined by collecting ≈ 50 middle leaflet pairs from middle leaves from terminals in the area of maximum limb spread of each tree (≈ 6 to 9 m high) between the second week of July and the first week of August each year (Plank, 1988). No nutrient sprays were applied, and leaves were visually clean and were not washed. Leaves were dried, ground to 20 mesh, and duplicate 1-g samples were analyzed for N by a macro-Kjeldahl procedure (Horwitz, 1980). Also, duplicate 1-g samples were ashed at 450C in a muffle furnace; the ash then was dissolved in 1.5 N HNO<sub>3</sub>, diluted, and P was determined calorimetrically by developing a yellow, vanadomolybdophosphoric acid color from the ash extract. Leaf K, Ca, Mg, Fe, Mn, and Zn were determined by atomic absorption spectrophotometry. Nutrients in soil were determined from 12 soil sample plugs randomly collected in winter from under the canopy of each tree. The samples were divided into 0–15- and 15–30-cm depths, dried, and analyzed for pH, P, K, Ca, and Mg by the procedures of Cahoon (1974). Nitrogen in Tifton loamy sand is very unstable and was not determined routinely. Residual nitrate N in soil taken in January following the last growing season was determined by the procedure of Baker and

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Smith (1969). Total N was determined by a Kjeldahl method (Horwitz, 1980).

Current season's terminal shoot growth was measured and crop density (number of fruit/terminal) was determined in the same area of the tree canopy and at the same time that leaf samples were collected. Twenty-five adjacent terminals were measured on each quadrant of the tree (100/tree), and the number of fruit (nutlets) present on the 25 terminals were counted. Trunk circumference was measured annually in the area of minimum circumference between the root flange and the first limb. Vigor and leaf color were rated visually for each tree in fall using an arbitrary rating of 1 to 9 (1 = lowest vigor/color, 9 = highest vigor/color).

Nuts harvested from individual trees were weighed, and quality determinations were made from a 50-nut ( $\approx 0.5$ -kg) sample. The in-shell nut sample was weighed and graded into size classifications by 0.16-cm increments of diameter. Edible kernels were graded into fancy, standard, and amber color grades as used by Goldkist Pecan Company (Waycross, Ga.), and percentages (of in-shell nut) of each grade, total percentage kernel, and nut weight were calculated. Edible kernels with defects and dark kernels were placed in the amber grade. Brightest kernels were graded fancy. Nuts from the orchard were consolidated and sold locally to the highest bidder each year. The average price paid for all 'Stuart' pecans bought each year by a pecan buyer-sheller based on kernel yield was used to calculate value of the nuts for 1973–1977. In subsequent years, the actual price received for the consolidated lot was used to calculate the value of nuts from each treatment. This value did not reflect differences in price that might have been obtained due to kernel grade or nut size, because all the nuts were sold as one lot.

The treatments were constructed so that 112 kg N/ha was applied to individual trees when the previous season's leaf N concentration was less than: 2.25% (N2.25), 2.50% (N2.50), 2.75% (N2.75), or 3.00% (N3.00). An additional treatment added 224 kg N/ha annually regardless of leaf analysis (AN). The Tifton soil is underlain by a compact layer of soil that limits root penetration. No buffer trees were used, but each year a subsoil furrow was plowed equidistant between trees in both directions to a depth of  $\approx 45$  cm that cut roots between trees. A previous study in the orchard revealed that practically all the roots were in the 15- to 45-cm soil layer (Worley et al., 1974). Nitrogen from ammonium nitrate was applied uniformly over a  $21 \times 21$ -m<sup>2</sup> area with the tree in the center during February or March of each year, as specified by the treatment for each tree.

Lime and nutrients other than N were added only when soil or leaf analysis indicated need. Trees were sprayed uniformly for insects and diseases to give effective control. An outbreak of methyl[1-(butylamino) carbonyl]-1H-benzimidazol-2-yl] carbamate (benomyl-) resistant downy spot caused leaf drop in July 1976, and, by September, most of the leaves had dropped. Consequently, yield was severely reduced in 1977. Orchard floor management was a closely mowed native sod, consisting mostly of crabgrass, bahaiagrass, common bermudagrass, and other native grasses, sedges, and weeds, with practically no legumes, with an herbicide strip in the tree row. Trees were not irrigated through 1980. Drip irrigation was provided thereafter when soil matric potential reached about  $-40$  kPa at either the 0–15-, 15–30-, or 30–45-cm depth.

A completely randomized design was used, with each treatment replicated seven times (eight for N2.25) in single-tree plots. Trees were not crowded, and limbs from one tree did not touch those from another. The data were analyzed using the General

Linear Models (GLM) program of SAS with mean separation by the PDIFF option (Helwig and Council, 1979). In cases where the year  $\times$  treatment interaction was significant, it was used as the error term for testing overall treatment means, and Duncan's multiple range test was used to test differences between means. Although the four thresholds progressed in units of 0.2570, the prescription nature of the applications makes them discontinuous; therefore, regression analysis was not appropriate.

## Results

*Nitrogen applied.* The amount of N required to meet the specifications of the treatments varied greatly from year to year, except for AN, which received the same application each year (Table 1). N2.25 required N applications for only a few trees in only four of the 16 years. At least one of the trees receiving N2.50 called for applications in 10 of the 16 years. In three years, none of the threshold treatments needed N applications. Over all years, N2.50 required more than three times the N needed for N2.25, and N2.75 required three times that used for N2.50. The differences in N applied for N2.75 and N3.00 were small in most years. N2.75 used only about one-third the amount of N application required for AN.

*Yield.* Yield varied greatly from year to year due to the alternate-bearing nature of pecans (Table 2). Very high-yielding years, such as 1975, 1978, and 1984, were followed by low-yielding years. Disease problems in 1976 probably reduced yields in both 1976 and 1977. Mean yield (kg/tree) for 16 years was similar for N2.25 and N2.50 treatments. Neither the N3.00 nor the AN treatments yielded more than N2.75. AN produced more nuts/tree (discussed later) than N3.00. This yield trend was generally consistent among years, but there were a few exceptions. AN was the highest-yielding treatment in 1973 and the lowest in 1974. AN also yielded more than all other treatments in 1983 and 1986. Yield was not significantly different among treatments in six of the 16 years. Nuts from the AN treatment brought an average of US\$1.32/tree per year more than N2.75. This difference was not statistically significant. The net income brought by N2.75 was \$2.73 more per tree per year than for AN.

*Tree growth, crop density, and appearance.* Neither trunk nor shoot growth increased in any treatments receiving N2.50 or more N (Table 3). Trunk circumference increased less for N2.25 than for any other treatment, and terminal shoot growth was less for N2.25 than any other treatment, except N2.50. Average crop density (fruit/terminal) was greater for AN and N3.00 than for N2.25 or N2.50 (Table 3). Vigor and color ratings (Table 3) did not reveal consistent differences among treatments within years. Vigor and color ratings were similar when averaged over years. Trees receiving the three highest N rates appeared more vigorous and darker green than trees receiving the two lowest NT treatments.

*Nut quality.* AN consistently produced smaller nuts than the low-N treatments (Table 4). Data for 1988 (Table 5) illustrate treatment differences for the size categories. Nuts from AN were mostly smaller than those from other treatments. Nitrogen rates as high as those applied to N2.75 did not decrease size grade significantly, except for 1974 (data not shown). There were no consistent differences among treatments for percentage kernel and kernel grade (data not shown). Over-year treatment averages were not significantly different for percentage kernel or percentage of kernels graded standard or amber. Fancy grade kernels averaged 9.7% for N2.25 and 6.5% for AN, and were

Table 1. Average N applied per hectare to all pecan trees in a treatment when applications were based on leaf N.

Leaf N <sup>z</sup> (%)	Nitrogen applied (kg·ha <sup>-1</sup> ) <sup>y</sup>																Cumulative <sup>x</sup> N applied
	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	
N2.25	14 a	0 a	0 a	0 a	0 a	42 a	0 a	0 a	28 a	0 a	0 a	28 a	0 a	0 a	0 a	0 a	115 a
N2.50	32 a	0 a	32 b	80 b	0 a	32 a	16 a	16 a	64 ab	0 a	0 a	96 b	0 a	16 a	16 a	0 a	400 b
N2.75	112 b	0 a	112 c	96 bc	112 b	96 b	96 b	96 b	112 b	16 a	112 b	112 b	0 a	96 b	80 b	0 a	1248 c
N3.00	112 b	0 a	112 c	112 c	112 b	112 b	112 b	112 b	112 b	112 b	112 b	112 b	0 a	112 b	112 c	0 a	1456 d
AN	224 c	224 b	224 d	224 d	224 c	224 c	224 c	224 c	224 c	224 c	224 c	224 c	224 b	224 c	224 d	224 b	3584 e

<sup>z</sup>Nitrogen at 112 kg·ha<sup>-1</sup> was applied to each tree only when the previous season's leaf analysis was below the specified thresholds of 2.25% (N2.25), 2.50% (N2.50), 2.75% (N2.75), or 3.00% N (N3.00), except that treatment (AN) received 224 kg·ha<sup>-1</sup> annually regardless of leaf analysis.

<sup>y</sup>Mean separation by GLM with PDIFF option at *P* = 0.05.

<sup>x</sup>Values are least square means and thus are slightly different from the sum for the years.

Table 2. Yield, value, and return for pecan nuts from 'Stuart' trees when N applications are based on leaf analysis.

Leaf N <sup>z</sup> (%)	Yield/tree (kg) <sup>y</sup>																Overall mean <sup>z</sup>	Mean value/ tree/ year (US\$)	Cost of N applied @ 0.64\$/kg	Returns above N costs (US\$)
	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988				
N2.25	63 a	66b	116a	15a	3a	78 a	18 a	37 a	44 a	37 a	23 ab	81 a	19 a	40 a	44 a	77 b	48 a	64 a	0.20	64
N2.50	91 b	42 a	126 a	15 a	12 a	88 ab	16 a	39 a	46 a	45 a	19 a	83ab	15 a	41 a	57 a	60 a	50 a	65 a	0.69	64
N2.75	105bc	76b	118a	35b	11 a	94 ab	30 a	50 b	49 a	47a	30ab	101c	23ab	57a	47 a	87 bc	60 b	82 b	2.16	80
N3.00	123c	45a	124a	25ab	8a	89ab	18a	44ab	41a	35 a	35 b	83 ab	25 ab	57 a	56 a	73 ab	55 a	71 ab	2.52	69
AN	125 c	37 a	134 a	31 b	6 a	100 b	18 a	43 ab	44 a	34 a	54 c	99 c	31 b	84 b	47 a	99 c	62 b	83 b	6.21	77

<sup>z</sup>Nitrogen at 112 kg·ha<sup>-1</sup> was applied to each tree only when the previous season's leaf analysis was below the specified thresholds of 2.25% (N2.25), 2.50% (N2.50), 2.75% (N2.75), or 3.00% N (N3.00), except that treatment AN received 224 kg·ha<sup>-1</sup> annually regardless of leaf analysis.

<sup>y</sup>Mean separation within years by GLM with PDIFF option at *P* = 0.05. Separation of overall mean yield and value was by Duncan's multiple range test, *P* = 0.05, due to a significant N treatment x year interaction.

<sup>z</sup>Values are least square means and thus are slightly different from the simple mean for the years.

<sup>x</sup>Value assumes equal prices received per kilogram of kernel prior to 1978 and per kilogram of in-shell nuts thereafter for all treatments.

Table 3. Pecan tree growth, appearance, and crop density as affected by N fertilization based on leaf analysis for 16 years.

Leaf N <sup>z</sup> (%)	Trunk		Crop density (fruit per terminally, Mean/year)	Mean rating <sup>x</sup>	
	circumference growth(cm) (total over years)	Terminal growth(cm) (total over years)		Vigor	Color
N2.25	31 a	139 a	0.90 a	5.6 a	5.5 a
N2.50	36 b	144 ab	0.93 ab	5.7 a	5.5 a
N2.75	39 b	154 b	1.04 bc	6.1 b	6.2 b
N3.00	39 b	151 b	1.09 c	5.9 b	6.1 b
AN	37 b	151 b	1.11 c	6.1 b	6.3 b

<sup>z</sup>Nitrogen at 112kg·ha<sup>-1</sup> was applied to each tree only when the previous season's leaf analysis was below the specified thresholds of 2.25% (N2.25), 2.50% (N2.50), 2.75% (N2.75), or 3.00% (N3.00), except that treatment AN received 224 kg·ha<sup>-1</sup> annually regardless of leaf analysis.

<sup>y</sup>Mean separation by GLM with PDIFF option at *P* = 0.05. Mean separation of vigor and color was by Duncan's multiple range test at *P* = 0.05 using the year x treatment interaction as the error term.

<sup>x</sup>Vigor rating and foliage color rating: 1 = low vigor and light green color, 9 = very vigorous or very dark green color,

the only significant treatment differences for percentage fancy grade kernels over years.

*Leaf analysis.* Leaf N usually increased with increasing N application; however, leaf N concentration for AN was higher than for N3.00 in only three years (Table 6). Doubling the N application rate from 112 kg·ha<sup>-1</sup> to 224 kg·ha<sup>-1</sup> thus made

very little difference in leaf N concentration in mid-summer. The average leaf N over years was well-above the threshold for N2.25, slightly above for N2.50, very close for N2.75, and below for N3.00(Table 7). The year x N treatment interaction was significant for leaf N, K, Ca, and Mn. Leaf P was lowest with the two highest N treatments and highest with the two lowest N applications, but the magnitude of the differences was small (Table 7). Leaf P was relatively low even though soil P was high for all trees. Average leaf K was lowest with AN and N2.75 and highest for N3.00. Average treatment differences for leaf Ca were significant, but the differences did not appear to be related to amount of N application. Leaf Mg was reduced by the two highest N rates. Trees receiving AN had leaves with Mn and Zn concentrations much higher than those receiving lower amounts of N. Differences in Fe and Cu, while significant statistically, were very small.

*Soil analysis.* Only data for the 0–15-cm soil layer are presented. Data for the 15–30-cm layer were similar, but the differences were of lower magnitude. Six applications of dolomite at 2240 kg·ha<sup>-1</sup> each were applied to maintain the soil pH near 6.0. These applications were uniform and thus the acid-forming effect of the N treatments is still reflected in soil pH. The lowest pH was with AN, and pH increased as N applications decreased (Table 8). Soil P increased with the higher N application rates, but was very high for all treatments. Soil K was in the medium range and was reduced by the higher N applications. Soil Ca and Mg were also very high for all treatments, but were also reduced by the higher N applications. Residual soil nitrate N at

Table 4. Pecan nut weight as affected by N application based on leaf analysis.

Leaf N <sup>z</sup> (%)	Nut wt (g/nut) <sup>y</sup>															
	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
N2.25	8.3 c	9.6 a	8.4 b	8.4 c	8.3 b	7.6 b	9.0 a	5.4 bc	9.7 c	8.1 bc	8.8 b	9.3 c	8.1 b	9.3 b	8.4 b	8.3 b
N2.50	7.5 bc	9.9 a	8.1 b	8.4 c	8.7 b	7.4 ab	9.0 a	5.4 bc	9.8 c	8.3 c	9.1 b	9.3 c	7.9 b	8.9 ab	8.5 b	8.4 b
N2.75	8.1 c	9.3 a	8.4 b	8.5 c	8.3 b	7.3 ab	9.2 a	5.8 c	9.5 c	8.0 bc	9.3 b	8.9 b	7.8 ab	8.7 ab	8.2 b	8.0 b
N3.00	6.7 ab	9.9 a	7.3 a	7.8 b	9.5 a	6.8 ab	9.0 a	4.8 b	8.7 b	7.7 ab	8.6 b	8.8 ab	7.6 ab	8.8 ab	7.1 a	7.9 b
AN	6.2 a	9.3 a	7.5 a	7.2 a	7.2 ab	6.6 a	8.5 a	4.2 a	7.8 a	7.5 a	7.8 a	8.5 a	7.1 a	8.3 a	6.8 a	7.3 a

<sup>z</sup>Nitrogen at 112 kg·ha<sup>-1</sup> was applied to each tree only when the previous season's leaf analysis was below the specified thresholds of 2.25% (N2.25), 2.50% (N2.50), 2.75% (N2.75) or 3.00%N(N3.00), except that treatment Unreceived 224 kg·ha<sup>-1</sup> annually regardless of leaf analysis.

<sup>y</sup>Mean separation within years by GLM with PDIFF option at *P* = 0.05.

Table 5. Percentage of pecan nuts in three size categories in 1988 as influenced by N application based on leaf analysis.<sup>a</sup>

Leaf N <sup>b</sup> (%)	Percentage of nuts with diameter <sup>c</sup>		
	19.2–20.6 mm	20.7–22.2 mm	22.3–23.8 mm
N2.25	9 a	60 b	27 ab
N2.50	7 a	56 ab	33 b
N2.75	13 a	57 ab	27 ab
N3.00	22 a	62 b	15 a
AN	41 b	43 a	13 a

<sup>a</sup>Data is for 1988 only. Most other years were similar.

<sup>b</sup>Nitrogen at 112kg·ha<sup>-1</sup> was applied only when the previous season's leaf analysis was below the specified thresholds of 2.25% (N2.25), 2.50% (N2.50), 2.75% (N2.75), or 3.00% N (N3.00), except that treatment AN received 224 kg·ha<sup>-1</sup> annually regardless of leaf analysis.

<sup>c</sup>Mean separation by GLM with PDIFF option at *P* = 0.05.

the end of the study ranged from 1.27 to 2.58 kg·ha<sup>-1</sup> for the lowest and highest application rates, respectively, and, while the difference is statistically significant, it is too low to be of practical significance. Total N ranged from 0.032% to 0.087% and was not related to treatments.

### Discussion

Many studies have been conducted on pecan trees where specified rates of N were applied annually and the trees' responses were measured. The grower who fertilizes by leaf analysis, however, is usually told to apply a nutrient only when its leaf concentration drops below the sufficiency range. I believe this to be the first report of a study where N was applied in this manner.

Most pecan growers apply at least 112 kg N/ha annually, and many apply 224 kg·ha<sup>-1</sup>. The present study indicates that application of 112 kg N/ha only when leaf N drops below 2.75%

produces yields equivalent to those for applications of 224 kg·ha<sup>-1</sup>; net monetary returns favored the lower rate. If the cost of applying the N and the lower price for the smaller nut size for the AN treatment is considered, the advantages for N application based on leaf N concentration are even greater. In some years, N applications could be completely omitted without loss of yield or tree growth.

Annual applications of high rates of N have the disadvantage of producing more small nuts and a lower percentage of fancy grade kernels. Large fancy grade kernels bring the best price. Apparently, more nuts were produced per tree for AN than for the lower thresholds, because yields were equal to or higher for AN than for the low thresholds. The N2.75 threshold appears to be the best compromise between nut size and yield.

Tree growth and appearance are also excellent indicators of the health of the tree. Growth of terminal shoots and in circumference were as good for N2.75 as for higher N applications. Tree appearance, as shown by vigor and color ratings, was also as good for N2.75 as for any other treatment. Vigor and color loss for thresholds <2.75 indicates that trees are in the deficiency range.

The increase in leaf N from N applications was expected, but the magnitude of the increase was very small when compared to the magnitude of the application differences. AN supplied 2128 kg more N/ha than N3.00, yet there was only a 0.05% increase in the average leaf N. Once trees are well-supplied with N, adding more makes little change in leaf N. When N was applied to trees with low thresholds, leaf N was increased and the depletion process was repeated. Apparently, the root and soil capacity to retain the applied N is saturated at relatively low rates of N, with the remainder lost to leaching. Soil N is so unstable in these soils that it is not determined routinely by the state soil testing service. Nitrates had practically all been leached or taken up by the tree at the end of the last growing

Table 6. Average pecan leaf N concentration for each treatment when N is applied to each tree only when leaf N drops below specified thresholds compared with annual applications.

Leaf N <sup>z</sup> (%)	Leaf N (%) <sup>y</sup>															
	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
N2.25	2.99 a	2.51 a	2.42 a	2.60 a	2.31 a	2.52 a	2.45 a	2.44 a	2.75 ab	2.64 ab	2.34 a	3.01 a	2.58 a	2.63 a	2.89 a	2.39 a
N2.50	3.06 a	2.53 a	2.43 a	2.70 ab	2.57 b	2.58 ab	2.53 ab	2.45 a	2.71 a	2.72 bc	2.38 ab	3.08 a	2.60 ab	2.64 a	3.04 b	2.25 a
N2.75	2.91 a	2.54 a	2.54 ab	2.59 a	2.63 b	2.62 ab	2.62 bc	2.59 b	2.89 c	2.61 a	2.49 bc	3.09 a	2.61 ab	2.68 ab	3.01 ab	2.72 b
N3.00	3.29 b	2.60 ab	2.64 b	2.77 b	2.70 bc	2.71 bc	2.66 c	2.67 b	2.81 abc	2.80 cd	2.65 d	3.30 b	2.71 b	2.79 b	3.22 c	2.66 b
AN	3.04 a	2.66 b	2.63 b	2.74 b	2.79 c	2.84 c	2.65 c	2.69 b	2.86 bc	2.86 d	2.56 cd	3.37 b	2.92 c	3.02 c	3.27 c	2.95 c

<sup>z</sup>Nitrogen at 112 kg·ha<sup>-1</sup> was applied to each tree only when the previous season's leaf analysis was below the specified thresholds of 2.25% (N2.25), 2.50% (N2.50), 2.75% (N2.75), or 3.00% N (N3.00), except that treatment AN received 224 kg·ha<sup>-1</sup> annually regardless of leaf analysis.

<sup>y</sup>Mean separation by GLM with PDIFF option at *P* = 0.05.

Table 7. Average pecan leaf analysis when N is applied based on leaf N thresholds or applied annually.

Leaf N <sup>z</sup> (%)	Dry wt (%) <sup>y</sup>					Dry wt (µg·g <sup>-1</sup> ) <sup>y</sup>			
	N	P	K	Ca	Mg	Mn	Fe	Cu	Zn
N2.25	2.59 a	0.137 c	1.06 ab	1.51 c	0.44 c	228 ab	81 a	9.3 d	109 a
N2.50	2.64 b	0.139 c	1.09 b	1.45 b	0.48 d	240 b	87 bc	9.0 bc	101 a
N2.75	2.70 c	0.136 c	1.02 a	1.50 bc	0.48 d	219 ab	89 c	9.0 c	137 b
N3.00	2.81 d	0.132 a	1.15 c	1.35 a	0.39 b	187 a	78 a	8.1 a	129 b
AN	2.86 e	0.133 ab	1.05 ab	1.52 c	0.34 a	393 b	83 ab	8.6 b	215 c
Year × N significant	Yes	No	Yes	Yes	No	Yes	No	No	No

<sup>z</sup>Nitrogen at 112 kg·ha<sup>-1</sup> was applied only when the previous season's leaf analysis was below the specified thresholds of 2.25% (N2.25), 2.50% (N2.50), 2.75% (N2.75), and 3.00% N (N3.00), except that treatment AN received 224 kg·ha<sup>-1</sup> annually regardless of leaf analysis.

<sup>y</sup>Mean separation by GLM ANOVA with PDIFF option at *P* = 0.05. If year × N treatment was significant, then mean separation was by Duncan's multiple range test.

Table 8. Average soil analysis (0–15-cm depth) when N applications to pecan were based on leaf N concentrations.

Leaf N <sup>z</sup> (%)	Soil pH	Soil concn (kg·ha <sup>-1</sup> ) <sup>y</sup>			
		P	K	Ca	Mg
N2.25	6.2 d	258 a	134 bc	2180 c	317 c
N2.50	6.1 d	293 b	152 d	2430 d	351 d
N2.75	6.0 c	300 b	139 c	1860 b	259 b
N3.00	5.9 b	327 c	128 ab	1820 b	253 b
AN	5.6 a	361 d	120 a	1520 a	196 a

<sup>z</sup>Nitrogen at 112 kg·ha<sup>-1</sup> was applied only when the previous season's leaf analysis was below the specified thresholds of 2.25% (N2.25), 2.50% (N2.50), 2.75% (N2.75), and 3.00% N (N3.00), except that treatment AN received 224 kg·ha<sup>-1</sup> annually regardless of leaf analysis.

<sup>y</sup>Mean separation for soil P by GLM with PDIFF option at *P* = 0.05. Mean separation for pH, K, Ca, and Mg by Duncan's multiple range test at *P* = 0.05 using the year × treatment interaction as the error term.

season. Nitrogen in the soil apparently was located in the soil organic matter that made up ≈ 2% of the soil. Leaching of the extra applied N could contaminate the ground water. Lowering of the soil pH by the high N rates increases the volatility of Mn and Zn; consequently, they were extremely high in leaves of trees receiving AN. I doubt that such concentrations present a problem with pecans, since they withstand high levels of Mn and Zn. A previous study did not show a yield response to increased pH from liming of old trees (Worley, 1974). If K and Mg were low, then high N applications could induce K or Mg deficiency. Potassium and Mg were not low in this study. The complexity of the P nutrition problem is illustrated by the increase in extractable soil P and the slight decrease in leaf P from increasing applications of N.

Since the crop removes very few nutrients (Hunter, 1956), pecan trees apparently act very similar to forest trees and thus are able to maintain nutrient levels much longer than row crops. Data from this study indicate that it is feasible to add 112 kg N/ha only in years when the previous season's leaf analysis was < 2.75% N, and that a sufficiency range of 2.75% to 3.30% N is satisfactory. This study did not address the upper limit for the sufficiency range.

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