8. Lundegardh, H. 1966. Plant Physiology, p. 325. N. Y. Amer. Elsevier Publishing Co., Inc.
9. Ulrich, A., and W. L. Berry. 1961. Critical phosphorus levels for lima bean growth. *Plant Physiol.* 36:626-632.
10. ———, and F. J. Hills. 1967. Principles and practices of plant analysis. *In*: Soil testing and plant analysis. Part II. Plant Analysis. SSSA Special Publication No. 2, Soil Sci. Soc. of Amer., Inc., Madison, Wisc.
11. Wallace, T. 1961. The diagnosis of mineral deficiencies in plants by visual symptoms. Chem. Publish. Co., Inc. N.Y.
12. Winston, W. J. 1966. Nitrogen in diagnostic criteria for plants and soils. Chapman, H. D. (ed.), pp. 310-323. University of California, Division of Agricultural Sciences.
13. Woolley, J. T., and T. C. Broyer. 1957. Foliar symptoms of inorganic elements in tomato. *Plant Physiol.* 32:148-151.

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Effect of N, P, K, and Lime on Yield, Nut Quality, Tree Growth, and Leaf Analysis of Pecan (*Carya illinoensis* W.)[1]

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Abstract. Mature 'Stuart' pecan trees in good condition on Tifton loamy sand did not respond to fertilizer [10-4.4-8.3 (N-P-K)] at rates from 0-1344 kg/ha annually over a 10-year period, but color and vigor of trees receiving no fertilizer were reduced near the end of the study. Highest yields were obtained with 448 kg/ha. Fertilizer effects on shoot growth and nut quality were inconsistent, but quality tended to be poorer for heavily fertilized than lightly fertilized trees near the end of the study. Fertilizer and limestone effects on yield and shoot growth were also inconsistent for mature 'Stuart' trees on Leefield sand at Waycross, Ga. over a 10-year period. Leaf analysis responded very slowly to nutrient application with leaf N and K being first increased by fertilizer application in the 6th and 9th years, respectively. Fertilizer P had little effect on leaf P. Liming to pH 6.0 with calcite increased leaf Ca and decreased leaf Mg and Al.

Yield and shoot growth of young 'Desirable' trees increased with the first 56 kg/ha increment of N, but further increases due to the second increment were seldom significant. Phosphorus and K additions had little effect on yield and shoot growth, but increasing K reduced nut size. Increasing N rates to 112 kg/ha improved vigor and color of trees. Leaf N and K for young trees increased from increasing application levels the first year, and leaf K was maintained in the desired range when soil test plus applied K equaled 112 kg/ha annually. Increasing N and K applications reduced leaf Mg, and increasing K applications increased leaf Mn, Fe, Al, and Na in young trees.

Problems of disease, weather, poor cultivars, etc. often make pecan returns from fertilizer application questionable (6, 7), but a recent survey (43) indicated that the highest yielding groves received over 1120 kg/ha of complete fertilizer annually. Whether such high applications are needed is questionable. Most of the nutritional work on pecans was done prior to the development of efficient pest control practices; hence, additional data are needed for trees under intensive care. Early studies indicated that yield or growth responses were obtained from complete fertilizer or N (10, 13, 30, 32-36). Pecan trees vary a great deal and are influenced by previous treatment (16); therefore, our tests were long-term studies.

Effects of fertilizer on kernel quality and nut size have been erratic. Complete fertilizer or N has been reported to increase (20, 21, 31), to have little effect (8, 17), and to lower (11, 18, 22, 23, 40) nut quality. Applications of complete fertilizer have increased nuts/lb count over applications of N alone (20). Complete fertilizer application has also increased (31), lowered (40), or had an erratic effect on (11) nut size. Oil content has been increased by N (12) and K (19) applications.

The relationship between leaf nutritional levels with application levels, soil test levels, yield, and growth is complex under field conditions. The increase in leaf levels from application of an element that is usually noted in annual crops is not always found for tree crops (3, 21), but surveys have shown that high yielding groves have higher leaf N than low yielding ones (14). Applications of fertilizer P have increased leaf P (2, 4, 21), but leaf P has been reported to be inversely correlated (28, 37), not correlated (3), and positively correlated (21) with yield. The influence of K application on leaf K and yield has also been erratic (3, 4, 21, 28, 29). Leaf Ca has been reported to be lower for unfertilized than for fertilized trees (21), not affected by cultural treatment (37), and not correlated with yield (3). Magnesium applications have increased leaf Mg, but .34% in leaves appeared sufficient (28). Leaf Mg was reduced as K application increased (29), and leaf Mg was not correlated with yield over the range of .46-.63% (3).

Some studies have attempted to establish deficiency and optimum ranges for various elements in pecan trees. In greenhouse sand culture experiments, trees grown without N, P, K, Ca, and Mg, leaf levels reached 1.20, 0.10, 0.12, 0.43, and 0.08%, respectively (1). Leaf N was optimum between 2.6-2.9% for 1-year-old seedlings (38), and K deficiency symptoms were found on leaves that had levels of 0.3% in similar greenhouse studies (42). These may or may not apply to old trees under field conditions. In one of Hunter and Hammar's tests (21) a dying tree contained 0.29% leaf K while a normal tree contained 0.53% leaf K.

Pecan leaf analysis has now become an accepted tool used by growers to maintain good nutrition of their groves and to determine which nutrients to apply (5, 45). Normal ranges for many of the nutritional elements in pecan leaves have been suggested (5, 38, 42, 45), but more research was needed to

[1]Received for publication December 21, 1972.
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[3]Thanks are expressed to Dr. J. B. Jones of the Soil Testing and Plant Analysis Laboratory, University of Georgia Cooperative Extension Service, for assistance with leaf analysis, to Dr. Ed Warren of the University of Georgia Computer Center for assistance with statistical analysis, to Dale Sherman, Vivian Mizelle, and H. M. Moore of the Abraham Baldwin College Center for Automation for providing computer service, and to Fred and Harold Voigt for use of their groves.

verify or correct the suggested ranges. We undertook to determine: 1) the effect of different fertilizer rates and lime on yield, tree growth, and nut quality of old and young pecan trees, 2) the effect of different fertilization and liming rates and methods on leaf analysis, 3) what fertilizer rates are required to bring leaf analysis within the suggested ranges, and 4) the time required to deplete nutrients from well-fertilized groves.

Materials and Methods

Kennedy 'Stuart' Grove. Trees were approx 40-year-old 'Stuarts' spaced 21 x 21 m on Tifton loamy sand near Tifton, Ga. Fertilizer rates of 10-4.4-8.3 (N-P-K) were 448 kg/ha biennially and 0, 448, 896, and 1344 kg/ha annually spread uniformly within the 21 x 21 m square in winter in 9 replications of single tree plots in a completely randomized design beginning in 1962. To restrict crossfeeding, the perimeter of each plot was subsoiled to 46 cm annually from 1962-69 and trenched to 1.2 m in 1970 and 1971. Crossfeeding was considered to be small.

Dolomite was applied at 2.2 metric tons/ha in February 1963. Zinc treatments as previously reported (46) were superimposed on the fertilizer treatments. Insects were controlled by appropriate insecticide application when a population increase occurred, and one or more applications of dodine, fentin hydroxide, or benomyl fungicides were used each year to control leaf fungus diseases. The scab disease was not a problem. Terminal shoot growth was determined by measuring current season's growth of 50 randomly selected terminals 6-8 m above ground on each tree. Tree circumference was measured each winter. Average cross-sectional trunk area/tree was 2225 sq. cm after the 1971 season. A 227-454 g subsample of nuts from each tree was graded for size and cracked. Kernels were graded into commercial grades of fancy (plump, well-developed kernels of bright color), standard (plump, well-developed kernels of darker color), and amber (darkest color kernels plus those edible kernels with defects) and expressed as percentage of the inshell nut.

Leaf samples, consisting of the middle leaflet pair of the middle leaf of exposed shoots without regard to fruiting, approx 6-8 m above the ground, were collected in early September 1962 and 1963 and early August, thereafter, except for 1969 when August leaves were destroyed in a laboratory accident, and mid-November leaves were used. From 1962-1967, leaves were ashed in a muffle furnace; then the ash was dissolved in 1.5 N HNO_3, diluted, and Zn, K, Ca, Mg, Mn, and Fe were determined by atomic absorption spectrophotometry. Phosphorus was determined colorimetrically from the ash extract by developing a yellow, vanadomolybdophosphoric-acid color. Nitrogen was determined by an official Kjeldahl process (26). After 1967 leaves were analyzed by the routine emission spectrographic and Kjeldahl procedures of Jones and Warner (25) and Warner and Jones (44). Additional analysis for Al, B, Cu, and sometimes Na were obtained after 1967.

Voigt 'Stuart' Grove, Waycross, Ga. Beginning in January of 1961, fertilizer treatments expressed as g N-P-K/cm circumference were applied to 21-year-old 'Stuart' pecan trees spaced 24 x 24 m apart on Leefield sand as follows: 1) 18-8-15, 2) 36-16-30, 3) 45-16-59, and 4) 89-16-59. Treatments 5 and 6 were identical to 1 and 4, respectively, until 1964 when P and K applications were discontinued. Fertilizer was applied uniformly underneath the tree's canopy. Beginning in 1963, limestone treatments of no lime, dolomite, and calcite were superimposed on each fertilizer treatment. Lime at 2.2 metric tons/ha was applied to the entire area allotted to each tree in winter or early spring of each year when soil pH dropped below 6.0 for dolomite and calcite treatments. The experimental design was a split plot with fertilizer treatments in whole plots of 12 trees each and limestone treatments in subplots of 4 trees each. The entire test was replicated twice. The grove was clean cultivated until 1968 when close mowing replaced cultivation as a cultural practice. Insecticides and fungicides were applied by the grove owner. No serious pest problem developed except for 1966 and 1967 when spittlebug was not controlled effectively. Yield in 1966 (<5 kg/tree) was too low to record. The tree row was elevated 1/3 - 2/3 m above the middle in order to facilitate drainage. Trenching revealed that tree roots from one tree did not extend under another. Terminal shoot growth was measured and leaf samples were collected and analyzed as for the Kennedy 'Stuart' Grove. Trunk cross-sectional area averaged 2194 sq. cm after the 1970 season.

Voigt 'Desirable' Grove, Waycross, Ga. Treatments were applied to 4-year-old 'Desirable' pecan trees growing in newly cleared Albany, Leefield, and Plumer sands near Waycross, Ga. beginning in 1966. These were poorly drained soils, but trees

Table 1. Annual yield, shoot growth, and percentage kernel of 'Stuart' pecans as affected by rates of 10-4.4-8.3 fertilizer – Kennedy Grove, Tifton, Ga.

Fertilizer rate (kg/ha)	Yield (kg/tree)^z										Cumulative yield^y
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	
0	0	66a	27a	38a	52a	21a	12a	55a	10a	78a	359ab
448 biennially	0	70a	23a	37a	57a	18a	20a	54a	11a	99ab	389ab
448 annually	0	79a	29a	40a	44a	15a	13a	79b	64a	105b	468b
896 annually	0	67a	22a	38a	47a	18a	15a	65ab	8a	94ab	374a
1344 annually	0	61a	24a	52a	53a	16a	22a	66ab	16a	98ab	408b
	Shoot growth (cm)^z										Cumulative shoot growth^y
0	6.9ab	15.1a	11.9a	15.2a	12.0a	10.0a	8.9a	10.5a	7.4ab	9.7a	107a
448 biennially	7.2ab	14.2a	12.6a	16.7ab	11.6a	11.2a	9.5ab	11.7ab	8.2b	10.0ab	114ab
448 annually	6.3a	17.5a	11.5a	17.4b	13.2a	11.7a	10.0abc	12.5b	7.0ab	11.7ab	116b
896 annually	7.2ab	15.0a	10.6a	15.5ab	11.7a	11.1a	10.7bc	10.9ab	6.5a	12.1b	111ab
1344 annually	8.2b	13.7a	11.9a	17.0ab	11.4a	13.1a	11.6c	10.9ab	6.7ab	12.0b	117b
	Percent kernel^z										
0	–	45ab	43a	50ab	49.7ab	49a	43.6ab	49a	45a	46b	
448 biennially	–	43a	41a	48a	49.2ab	48a	43.8ab	49a	46a	45b	
448 annually	–	47b	43a	51b	49.7ab	50a	44.1ab	46a	44a	45b	
896 annually	–	44ab	42a	50ab	48.6a	49a	42.0a	46a	44a	42a	
1344 annually	–	45ab	44a	49a	50.0b	49a	44.3b	46a	47a	41a	

^{z}Yield, shoot growth, and percentage kernel means with the same letter within a column are not significantly different at 5%.

^{y}Cumulative yield and cumulative shoot growth are not always sums of year yields due to rounding and omission of some trees from cumulative totals because of nut loss due to squirrels.

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were planted on ridges approx 2/3 m higher than the middles between the trees to facilitate drainage. Trees were spaced approx 18 m apart, and trees were too small for root crossfeeding. Nitrogen and P rates were 0, 56, and 112 kg/ha; K rates were 0, 112, and 224 kg/ha. Treatments were in a complete factorial arrangement in a randomized complete block design with 4 replications and single tree plots. All treatments were applied by hand to an area within a 3 m radius of the trunk in 1966 and a 3.66 m radius, thereafter. The N treatments were all applied annually, but the 0-15 cm soil test level for P and K was deducted from the respective treatment level for P and K for each tree, and the difference was the amount applied each spring. Tree circumference, kernel quality, and nut size were determined as for the Kennedy Grove. Diseases and insects were controlled by recommended insecticides and fungicides applied by the grower. There were no serious insect and disease problems. Nutlets were counted on 100 terminal shoots at random around the periphery of the tree on May 26, 1969 and May 28, 1970, and the average number of nuts/terminal was calculated. Leaf samples were collected and terminal shoot growth measurements were made from the mid to top portion of the tree's height. Leaf analysis was similar to the Kennedy 'Stuart' Grove. Trunk cross-sectional area averaged 256 sq. cm after the 1970 season.

Table 2. Annual yield and shoot growth of pecans as affected by various fertilizer formulas with rates based on tree circumference - Voigt 'Stuart' Grove, Waycross, Ga.

Fertilizer rate (g/cm circumference) N - P - K	Yield (kg/tree)[z] 1965	1968	1969	1970	Cumulative yield[w]
1 18 - 8 - 15	59a	50bc	49a	54a	404a
2 36 - 16 - 30	79a	44ab	56a	74a	458a
3 36 - 16 - 59	57a	51bc	61a	61a	434a
4 45 - 16 - 59	72a	60c	41a	78a	472a
5 18 - 0 - 0[y]	68a	39a	35a	82a	412a
6 89 - 0 - 0[y]	54a	45ab	59a	59a	411a
Limestone treatment					
1 No lime	69a	46a	60b	64ab	452b
2 Dolomite[x]	61a	52b	39a	78b	430ab
3 Calcite[x]	64a	46a	51ab	60a	414a

[z]Yield and shoot growth means for fertilizer and limestone treatments with the same letter within columns are not significantly different at the 5% level of Duncan's multiple range test.

[y]Treatments 5 and 6 were identical to 1 and 4, respectively, until 1964 when P and K were omitted.

[x]Lime at 2.24 metric T/ha (1 T/acre) was applied when pH under each tree dropped below 6.0 with first adjustments beginning in 1963.

[w]Cumulative yield and cumulative shoot growth include the 10-year period 1961-1970.

Results

Yield. Yield differences in the old groves due to treatments were small. Alternate bearing caused a complete crop failure in the Kennedy Grove in 1962, but yield was relatively high in '63, '66, '69, and '71 (Table 1). Significant differences did not occur until 1969 when yields were higher when 448 kg/ha 10-4.4-8.3 was applied annually than when lower rates were used. Similar results were obtained in 1971. For cumulative yield, no 10 years, cumulative yields favored the no lime over the calcite treatment (Table 2).

Yield of young 'Desirable' trees increased greatly with the first 56 kg increment of N, but the additional increase for the second 56 kg increment was not significant after the 2nd year. Cumulative yields were similar (Table 3). Yield did not respond to P and K treatments and interactions were not significant. The treatment yielded significantly more than the unfertilized check. Similarly for the Voigt 'Stuart' Grove yield differences were significant in only 1 of 10 years, and cumulative yields were never affected significantly (Table 2). Differences due to limestone treatments were not consistent within years; but after

Table 3. Effect of N on yield and nutlet set of young 'Desirable' pecan trees - Waycross, Ga.

Treatment (kg/ha)[z]	Yield (kg/tree)[y] 1967	1968	1969	1970	Cumulative yield 1970	Nutlets/shoot in spring 1969	1970
N_0	.5a	1.9a	4.3a	2.9a	9.76a	2.06a	1.21a
N_{56}	.7a	2.6b	5.8b	5.8b	15.2b	2.38a	1.81b
N_{112}	.8b	3.6c	6.5b	6.9b	17.7b	2.41a	2.25c

[z]Differences for P and K treatments were not significant.

[y]Mean separation, within a year, by Duncan's multiple range test at 5%.

spring nutlet set increased with each increment of N, but the increase was significant only in 1970 (Table 3).

Tree growth. Tree growth behaved rather erratically over years for the old groves; but during the latter part of the study, terminal shoot growth was usually reduced when no fertilizer

Table 4. Effect of N and K treatments on terminal shoot growth and tree size of pecan - Young 'Desirable' Grove, Waycross, Ga.

Annual treatment (kg/ha)	Terminal shoot growth (cm)[y] 1966	1967	1968	1969	1970	Cumulative shoot growth (cm)[y] 1970	Circumference (cm)[y] 1970
N_0	66a	55a	38a	37a	19a	216a	51a
N_{56}	71b	65b	43b	41b	23b	243b	58b
N_{112}	76b	64b	42b	42b	23b	247b	64c
K_0	68a	59a	40a	37a	22a	227a	58a
K_{112}[z]	70a	61a	41a	41b	22a	235ab	56a
K_{224}[z]	76b	64a	43a	41b	21a	244b	58a
Interactions	NS	NS	NS	NS	NS	NS	NS

[z]Treatment level was the soil test level in topsoil + applied level.

[y]Mean separation, within a year, by Duncan's multiple range test at 5%. Differences between P levels were not significant for above parameters.

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was applied in the Kennedy Grove (Table 1). Cumulative shoot growth was lower for unfertilized trees than for those fertilized with 448 or 1344 kg 10-4.4-8.3 annually. Circumference growth was least for unfertilized trees (33 cm) and greatest for those receiving the heaviest rate (41 cm). Differences between other treatments were not significant. Terminal shoot growth differences and circumference growth differences due to treatment in the Voigt 'Stuart' Grove were either not significant or inconsistent.

Growth increases in the young 'Desirable' Grove due to N application were readily apparent by the first year. The first 56 kg increment of N increased terminal shoot growth, but the second increment did not increase it further (Table 4). Each increment of N increased circumference growth (Table 4). Either the first (1969) or the second (1966) increment of K increased shoot growth over that from the K_0 plots (Table 4). Phosphorus treatments and interactions had little effect on tree growth.

Kernel quality. High rates of fertilization did not increase kernel quality. In the Kennedy Grove, nuts/kg count (not shown) and percentage kernel (Table 1) behaved erratically over years, but increasing the fertilizer rate lowered percentage kernel in 1971 (Table 1), and percentage fancy kernels in 1970 and 1971, and to some extent in 1969 (Table 5). In the young grove, increasing N rates decreased total percentage edible kernel very slightly in 2 years, and increasing P levels has no significant effect on quality (Table 6). The first or second increment of K increased nuts/kg count in 2 years. Percentage total edible kernel was greatest with the medium K level. Percentage of any kernel decreased with increasing K. The percentage of nuts in the largest size category was reduced with increasing K (Table 6).

Tree appearance. Differences in tree appearance due to treatment were slow to appear for the old trees in the Kennedy Grove but were readily apparent after 1968. Trees receiving no fertilizer on the biennial application developed less dense foliage with lighter green color than trees receiving higher rates (Table 7). Little visual differences in tree appearance could be detected in the Voigt 'Stuart' Grove. On the other hand, an increase in vigor and color was apparent with increasing N levels every year in the young 'Desirable' Grove (Table 8). The first increment of K increased vigor in 1969 and color in 1968 and 1969 but reduced color in 1970 (Table 8). Phosphorus applications and interactions had little effect.

Table 5. Effect of fertilizer rates on the percentage of the nut wt made up of fancy grade kernels - Kennedy Grove, Tifton, Ga.

Fertilizer rate (10-4.4-8.3 kg/ha)	Percentage fancy kernels[z]		
	1969	1970	1971
0	28ab	13b	39b
448 biennially	30b	10ab	38b
448 annually	27ab	9ab	36ab
896 annually	22a	9ab	31a
1344 annually	23ab	8a	31a

[z]Mean separation, within a year, by Duncan's multiple range test at 5%.

Table 7. Effect of fertilizer rates on pecan tree vigor 8 - 10 years after treatments were initiated.

Fertilizer rate (10-4.4-8.3 kg/ha)	Vigor rating[zy]		
	1969	1970	1971
0	6a	4a	4a
448 biennially	6a	6b	6b
448 annually	8b	6b	8c
896 annually	8b	8c	8c
1344 annually	8b	8c	8c

[z]Vigor rating was 0 = poor; 9 = very vigorous.
[y]Mean separation, within a year, by Duncan's multiple range test at 5%.

Leaf N. For the old groves, differences in leaf N due to treatment were also slow to appear being first significant in the Kennedy Grove in 1967 (Table 9). By 1967 increasing fertilizer rates to moderate levels increased leaf N. The low levels in 1969 were due to sampling in November. Leaf N was never significantly higher for the 1344 kg/ha rate than the 896 kg/ha rate. Leaf N was never below 2.5% until 1968 even when no fertilizer had been applied. In the Voigt 'Stuart' Grove, differences were significant in only 2 of 10 years (Table 10).

In the young 'Desirable' Grove, the increase in leaf N with increasing applications of N was apparent from the beginning (Table 11). The leaf N level was much lower in the 'Desirable' Grove than in the older groves.

Leaf P. Although some treatment differences were significant for leaf P, the magnitude of the differences was so small that they were of little practical significance. Leaf P was higher for the highest rate than for the lowest rate of fertilization in the Kennedy Grove in 1970 and 1971 (Table 9). Similarly in 1966 and 1970, increasing the P application rate in the Voigt 'Stuart' Grove increased leaf P slightly. In the 'Desirable' Grove, N and K treatments reduced leaf P slightly, but P treatments had little effect (Table 11).

Leaf K. Fertilizer treatments did not have a great effect on leaf K in the old groves but did affect it in the young grove. In the Kennedy Grove, none of the treatments increased leaf K significantly above that of the unfertilized check in any year (Table 9). In only 2 years in the Voigt 'Stuart' Grove, leaf K was less where annual K applications had been discontinued than where they were continued (Table 10). Also, leaf K was lower when soil was limed with dolomite than when limed with calcite

Table 6. Effect of N, P, and K on pecan quality and size parameters - Young 'Desirable' Grove, Waycross, Ga.

Annual treatment (kg/ha)	Nuts/kg count[y] 1969	Nuts/kg count[y] 1970	Total percentage edible kernel[y] 1968	Total percentage edible kernel[y] 1969	Total percentage edible kernel[y] 1970	Percentage fancy kernel[y] 1968	Percentage >2.54 cm nuts[y] 1968	Percentage >2.54 cm nuts[y] 1969	Percentage >2.54 cm nuts[y] 1970
N_0	112a	99a	52.1b	53b	53a	29a	61a	25a	76ab
N_{56}	112a	101a	51.5ab	53b	52a	29a	52a	23a	70a
N_{112}	112a	99a	50.9a	52a	52a	28a	55a	26a	78b
P_0	115a	101a	51.7a	52a	52a	28a	55a	24a	73a
P_{56}[z]	112a	99a	51.3a	52a	52a	29a	60a	27a	75a
P_{112}[z]	112a	99a	51.6a	53a	53a	30a	54a	23a	76a
K_0	110a	97a	50.8a	52a	52a	33c	70c	41b	83b
K_{112}[z]	112a	101b	52.3b	53a	53b	29b	54b	19a	68a
K_{224}[z]	115b	101b	51.4ab	52a	52ab	25a	45a	14a	72a
Interactions	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Treatment levels included the soil test level in the 0-15 cm layer + the amount applied.
[y]Mean separation, within a year, by Duncan's multiple range test at 5%.

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Table 8. Effect of N, P, and K treatments on pecan tree vigor and foliage color - Young 'Desirable' Grove, Waycross, Georgia.

Annual treatment (kg/ha)	Vigor rating^y 0 = poor; 9 = excellent			Color rating^y 0 = light green; 9 = dark green			
	1968	1969	1970	1967	1968	1969	1970
N_0	4.9a	4.5a	4.1a	4.6a	1.7a	4.7a	3.8a
N_{56}	6.9b	6.0b	5.8b	5.3b	4.5b	5.6b	4.3a
N_{112}	7.4b	6.9c	6.6c	5.7c	6.4c	7.3c	5.7b
P_0	6.4a	5.6a	5.1a	5.3a	4.1a	5.7a	4.1a
$P_{56}{}^z$	6.3a	5.8a	5.7ab	5.2a	4.6a	6.3a	5.1b
$P_{112}{}^z$	6.5a	5.9a	5.8b	5.1a	4.0a	5.6a	4.6ab
K_0	6.3a	5.3a	5.5a	5.1a	4.0a	5.4a	5.1b
$K_{112}{}^z$	6.4a	6.0b	5.5a	5.3a	4.7b	6.1b	4.3a
$K_{224}{}^z$	6.6a	6.0b	5.6a	5.2a	3.9a	6.1b	4.4ab
Interactions	NS	NS	NS	NS	NS	NS	NS

^{z}Treatment levels included the soil test level in the 0-15 cm layer plus the amount applied.

^{y}The N, P, and K treatment within the same column with the same letter are not significantly different.

(Table 12). With the young trees, however, each increment increase in the K treatment level caused a significant increase in leaf K (Table 11).

Leaf Ca. Fertilizer treatments also were slow to affect leaf Ca in the old groves. Toward the end of the study leaf Ca was increased by increasing the fertilization level in the Kennedy Grove (Table 9), but fertilizer rates had no effect on leaf Ca in the Voigt 'Stuart' Grove (not shown). In the 'Desirable' Grove, leaf Ca was not affected by N or P treatments but reached its highest level with the medium rate of K (Table 11). Leaf Ca was greatest when trees in the Voigt 'Stuart' Grove were limed with calcite, intermediate when limed with dolomite, and least when no lime was used (Table 12).

Leaf Mg. Leaf Mg reacted differently in the 3 groves. In the Kennedy Grove, a significant quadratic trend was apparent each year after 1963 with leaf Mg increasing with increasing rates of fertilizer through 448 kg/ha annually, then decreasing as fertilizer rate increased further (Table 9). In the Voigt 'Stuart'

Table 9. Effect of fertilizer on pecan leaf analysis - Kennedy Grove, Tifton, Ga.

Rate of 10-4.4-8.6 (N-P-K) kg/ha	1962	1963	1964	1965	1966	1967	1968	1969^z	1970	1971
					Leaf N (%)^y					
0	2.66a		2.58a	2.89a	2.64a	2.58a	2.36a	2.09a	2.52a	2.44a
448 biennially	2.69a		2.60a	2.90a	2.63a	2.66ab	2.44ab	2.11ab	2.63b	2.64b
448 annually	2.65a	not	2.63a	2.92a	2.69a	2.67ab	2.44ab	2.12ab	2.59ab	2 66b
896 annually	2.69a	avail.	2.65a	2.93a	2.65a	2.70b	2.52bc	2.26b	2.72c	2.96c
1344 annually	2.72a		2.65a	2.92a	2.65a	2.69b	2.56c	2.18ab	2.74c	2.79b
					Leaf P (%)^y					
0	.12ab	.125ab	.14a	.14a	.13a	.13a	.16a	.17a	.17a	.175a
448 biennially	.12ab	.126ab	.14a	.13a	.12a	.13a	.16a	.17a	.17a	.178ab
448 annually	.13b	.134c	.14a	.14a	.13a	.13a	.17a	.18a	.17a	.186ab
896 annually	.12ab	.127bc	.14a	.13a	..13a	.13a	.16a	.17a	.17a	.182ab
1344 annually	.11a	.119a	.14a	.14a	.13a	.13a	.17a	.18a	.19b	.189b
					Leaf K (%)^y					
0	1.06a	.84a	1.08ab	1.03a	1.06a	.99a	1.08a	.99a	1.11ab	1.04ab
448 biennially	1.13a	.90a	1.06ab	1.06a	1.00a	1.05a	1.07a	1.01a	1.12ab	1.00ab
448 annually	1.10a	.78a	.96a	.97a	.96a	.96a	1.00a	1.11a	1.07a	.93a
896 annually	1.11a	.82a	1.10b	1.08a	1.01a	1.01a	1.01a	1.21a	1.10ab	.96ab
1344 annually	1.21a	.90a	1.05ab	1.03a	1.07a	1.12a	1.07a	1.20a	1.28b	1.12b
					Leaf Ca (%)^y					
0	1.41a	1.25a	1.22a	.84a	1.06a	1.00a	1.18a	1.47a	1.15a	1.24a
448 biennially	1.59a	1.33a	1.29a	.92a	1.17b	1.00a	1.23ab	1.48a	1.19a	1.24a
448 annually	1.65a	1.28a	1.35a	.81a	1.13ab	1.02a	1.26ab	1.62a	1.19a	1.30ab
896 annually	1.53a	1.20a	1.32a	.94a	1.17b	1.00a	1.19a	1.43a	1.21a	1.34ab
1344 annually	1.65a	1.29a	1.35a	.92a	1.13ab	1.02a	1.36b	1.62a	1.40b	1.50b
					Leaf Mg (%)^y					
0	.26a	.26ab	.25ab	.25ab	.23ab	.27b	.34a	.28ab	.30a	.38ab
448 biennially	.29a	.31b	.28ab	.27ab	.28ab	.28b	.35a	.31ab	.33a	.39ab
448 annually	.24a	.30b	.30b	.31b	.30b	.30b	.43b	.36b	.37a	.47b
896 annually	.30a	.27ab	.27ab	.28ab	.28b	.29b	.35a	.28ab	.35a	.39ab
1344 annually	.23a	.22a	.21a	.21a	.19a	.20a	.29a	.22a	.29a	.27a
					Leaf Mn (ppm)^y					
0	538a		299a	277a	187a	251ab	223a	312a	283a	314a
448 biennially	654a		384a	326a	228a	237ab	221a	300a	283a	344a
448 annually	604a		350a	340a	224a	223a	218a	318a	287a	355a
896 annually	561a		411a	304a	230a	259ab	274ab	397ab	348a	364a
1344 annually	591a		398a	319a	233a	304b	330b	511b	524b	576b

^{z}Leaf analysis for 1969 was from Nov. 10 leaf samples. Other leaves were sampled in early August.

^{y}Mean separation, within a year, by Duncan's multiple range test at 5%.

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Table 10. Effect of fertilizer treatment on pecan leaf N, P, K, and Mg - Voigt 'Stuart' Grove, Waycross, Ga.

Treatment No.	Fertilizer treatment g/cm of circumference N - P - K	Leaf N (%)[zy] 1966	Leaf N (%)[zy] 1968	Leaf P (%)[zy] 1966	Leaf P (%)[zy] 1970	Leaf K (%)[zy] 1966	Leaf K (%)[zy] 1970	Leaf Mg (%)[zy] 1970
1	18 - 8 - 15	2.63a	2.66a	.142ab	.188abc	.92b	.97ab	.37bc
2	36 - 16 - 30	2.76a	2.84c	.143ab	.197bc	.92b	1.00ab	.31ab
3	45 - 16 - 59	2.72a	2.82bc	.150b	.197bc	.96b	1.08b	.32ab
4	89 - 16 - 59	2.98b	2.84c	.150b	.198c	.92b	.99ab	.29a
5	18 - 0 - 0[x]	2.57a	2.66a	.135a	.173a	.75a	.81a	.38c
6	89 - 0 - 0[x]	2.73a	2.72ab	.135a	.180ab	.73a	.80a	.34abc

[z]Leaf analysis for years from 1962-1970 not shown in the table showed no significant treatment differences.
[y]Mean separation, within a year, by Duncan's multiple range test at 5%.
[x]Treatments 5 and 6 were identical to 1 and 4, respectively, prior to 1964.

Grove, differences in leaf Mg due to fertilizer treatment were significant only in 1970 when increasing K rates decreased leaf Mg (Table 10). Leaf Mg was highest when dolomite was the lime source, intermediate when trees were not limed, and least when calcite was the lime source (Table 12), but differences were not significant until 1966. In the young grove, increasing either the N or K treatment levels decreased leaf Mg. Differences became more pronounced with time (Table 11).

Leaf Mn. High fertilization tended to increase leaf Mn. In the Kennedy 'Stuart' Grove, leaf Mn was higher for the highest fertilization rate than for one or more of the lower rates each year after 1966 (Table 9). Similar trends were observed in the Voigt 'Stuart' Grove when increasing rates of N or complete fertilizer increased leaf Mn (Table 13). Increasing the K level in the Voigt 'Desirable' Grove also increased leaf Mn in 1966-68 (Table 11).

Leaf Al. Leaf Al was very high in all plots and tended to increase with increasing fertilization. By 1970 and 1971, Kennedy Grove leaf samples increased as fertilizer rates increased (except for the 896 kg/ha rate) (Table 14). A similar trend with increasing N or complete fertilizer was observed in the Voigt 'Stuart' Grove (Table 15). Liming reduced leaf Al (Table 15). In the young 'Desirable' Grove, the first (1969) or first and second (1970) increment of K caused a striking increase in the leaf Al level (Table 11).

Other leaf elements. Some responses to the fertilizer treatments were noted for other elements in one or more years. Liming reduced leaf Sr (not shown). Increasing the K application increased leaf Fe, Ba, and Na and increasing N application reduced leaf B and Na and increased leaf Ba (Table 11).

Correlations with yield. Very few of the variables measured were significantly and consistently correlated with yield in the 'Desirable' Grove. When up to 50 variables were correlated, only tree circumference, leaf Ba, leaf Mn, color rating, vigor rating and nutlet count were significantly positively correlated with yield in each year that they were measured (Table 16).

Table 11. Effect of N and K applications on pecan leaf analysis for young 'Desirable' trees - Waycross, Ga.

Nutrient and rate (kg/ha)	Leaf N (%)[z]					Leaf P (%)[z]					Leaf K (%)[z]				
	1966	1967	1968	1969	1970	1966	1967	1968	1969	1970	1966	1967	1968	1969	1970
N_0	2.03a	2.16a	2.46a	1.89a	2.12a	.146b	.135a	.145b	.179b	.168b	1.10b	.89b	.90a	.83a	.98a
N_{56}	2.12b	2.25b	2.54b	1.89a	2.09a	.133a	.132a	.137a	.163a	.160a	.89a	.78a	.86a	.82a	.99a
N_{112}	2.27c	2.28b	2.60c	2.00b	2.22b	.144b	.131a	.136a	.153a	.157a	.88a	.80a	.89a	.85a	.96a
K_0	2.12a	2.23a	2.51a	1.93a	2.16a	.147b	.136a	.141a	.172b	.162a	.72a	.60a	.59a	.54a	.58a
K_{112}[y]	2.14a	2.25a	2.53a	1.93a	2.10a	.140ab	.132a	.140a	.166ab	.162a	.94b	.76b	.92b	.81b	.92b
K_{224}[y]	2.16a	2.21a	2.56a	1.91a	2.17b	.136a	.129a	.137a	.157a	.160a	1.22c	1.10c	1.13c	1.16c	1.42c

Nutrient and rate (kg/ha)		Leaf Ca (%)[z]					Leaf Mg (%)[z]					Leaf Mn (ppm)[z]			
N_0		.85a	1.35a	1.18a	.87a	.33a	.26a	.28b	.32b	.40b	352a	185a	221a	243a	244a
N_{56}		.83a	1.35a	1.17a	.83a	.32a	.26a	.25a	.29a	.37ab	366a	190a	219a	265a	290b
N_{112}		.86a	1.33a	1.17a	.83a	.32a	.26a	.25a	.27a	.35a	369a	193a	236a	263a	267ab
K_0		.81a	1.30a	1.11a	.87b	.35b	.28b	.28c	.35c	.44c	311a	168a	186a	218a	247a
K_{112}[y]		.89b	1.39b	1.29b	.89b	.33b	.26b	.26b	.31b	.38b	364b	179a	226b	267a	278a
K_{224}[y]		.85ab	1.33ab	1.12a	.77a	.30a	.23a	.23a	.22a	.29a	413c	220b	264c	286a	276a
Interactions	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Nutrient and rate (kg/ha)	Leaf Al (ppm)[z] 1969	Leaf Al (ppm)[z] 1970	Leaf Fe (ppm)[z] 1966	Leaf Fe (ppm)[z] 1967	Leaf Fe (ppm)[z] 1969	Leaf Fe (ppm)[z] 1970	Leaf B (ppm)[z] 1969	Leaf B (ppm)[z] 1970	Leaf Ba (ppm)[z] 1969	Leaf Ba (ppm)[z] 1970	Leaf Na (ppm)[z] 1970
N_0	1534a	1283a	181b	50a	110a	94a	62b	39b	55a	38a	81b
N_{56}	1454a	1184a	170b	47a	123a	102a	57a	34a	53ab	34a	71ab
N_{112}	1518a	1077a	121a	47a	98a	98a	57a	35a	63b	39a	65a
K_0	929a	718a	165a	43a	89a	77a	59a	37a	43a	30a	57a
K_{112}[y]	1805b	1281b	155a	49ab	122b	103ab	59a	36a	60b	37a	73b
K_{224}[y]	1773b	1546c	152a	51b	118ab	114b	58a	35a	68b	44b	86c
Interactions	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Mean separation, within a year, by Duncan's multiple range test at 5%. Data for P treatments were omitted.
[y]Treatment levels are 0-15 cm soil test plus applied levels.

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Table 12. Pecan leaf K, Ca and Mg as affected by limestone application – Voigt 'Stuart' Grove, Waycross, Ga.

Limestone treatment	1965	1966	1967	1968	1969	1970
			Leaf K (%)^{zy}			
No lime	.82a	.87ab	.93a	1.06ab	.81ab	.97b
Dolomite^{x}	.84ab	.83a	.91a	1.02a	.78a	.85a
Calcite^{x}	.90b	.90b	.99a	1.10b	.86b	1.00b
			Leaf Ca (%)^{zy}			
No lime	.98a	1.26a	1.26a	1.22a	2.31a	1.28a
Dolomite^{x}	1.09a	1.30ab	1.34ab	1.29ab	2.33a	1.42b
Calcite^{x}	1.11a	1.36b	1.38b	1.35b	2.64b	1.65c
			Leaf Mg (%)^{zy}			
No lime	.35a	.37ab	.28b	.28b	.33b	.32b
Dolomite^{x}	.36a	.39b	.31b	.32c	.37c	.40c
Calcite^{x}	.32a	.33a	.24a	.24a	.27a	.28a

^{z}Mean separation, within a year, by Duncan's multiple range test at 5%.

^{y}Differences due to limestone treatment were not significant in 1963 and 1964.

Discussion

The condition of the grove at the beginning of the study determines greatly the responses that were obtained. The Kennedy 'Stuart' Grove had been well fertilized and tree appearance was good when the fertilizer treatments were initiated in 1962. Residual soil P was high and residual soil K was medium to high at depths to 75 cm by the end of the study even on plots that had received no fertilizer. Also, leaf levels of P and K were within or above the suggested normal ranges for leaf analysis (5, 45) and was affected very little by treatments, which further indicates that P and K were adequate. The few changes that were observed in this grove due to treatments, therefore, were probably mainly due to the N in the treatments. The long residual effect even for N is evident, since significant differences in leaf N due to treatment did not occur until the 6th year of the study. Visual differences in tree appearance began to occur about 6 years after the treatments began, and N deficiency was easily detected by loss of vigor and green color intensity at the end of the study. Yield also began to drop in unfertilized plots during the last 4 years of the study as a further indication that N was finally becoming depleted. An annual application of only 448 kg of 10-4.4-8.3 (N-P-K)/ha, however, was sufficient to maintain high yield, good shoot growth, and relatively high quality. Also, leaf N was usually maintained at suggested levels with this rate. Sparks (38) also found leaf levels of 2.6-2.9% to be adequate for leaf N. Since symptoms of vigor loss were occurring at leaf N levels around 2.5% or less for August samples, it is felt that the range for normal leaf N levels should not be lowered below 2.5% for old 'Stuart' trees. The upper limit for the normal range of 3.0%, which is presently used by some laboratories, was seldom reached regardless of the amount of N applied in our studies; however, grower's samples frequently exceed 3.0% N. The high rates of fertilization reduced quality in some years as shown by percentage of kernel and percentage of fancy kernel, perhaps by keeping the trees more vegetative for longer periods, which may delay curing of the kernel.

The Voigt 'Stuart' Grove also had been well fertilized when

Table 13. Pecan leaf Mn as affected by different fertilizer formulas – Waycross, Ga.

Treatment number	Fertilizer treatment g/cm of circumference N P K	Leaf Mn (ppm)^{z} 1963	1964	1965	1966	1967	1968	1969	1970
1	18 – 8 – 15	376a	402a	536ab	369a	371b	330b	311a	604b
2	36 – 16 – 30	497ab	467a	613ab	392a	393bc	392c	396a	750c
3	45 – 16 – 59	506ab	489a	616ab	419a	397c	398c	396a	712c
4	89 – 16 – 59	633b	622a	841c	485a	400c	400c	424a	844d
5	18 – 0 – 0^{y}	456a	386a	487a	293a	257a	227a	240a	352a
6	89 – 0 – 0^{y}	515ab	574a	652b	349a	396c	399c	342a	582b

^{z}Mean separation, within a year, by Duncan's multiple range test at 5%.

^{y}Treatments 5 and 6 were identical to 1 and 4 from 1961-1963.

Table 14. Effect of fertilizer on pecan leaf Al – Kennedy Grove, Tifton, Ga.

Rate of 10-4.4-8.3 (N-P-K) kg/ha	Leaf Al (ppm)^{z} 1970	1971
0	1314a	745a
448 biennially	1596ab	1304b
448 annually	1730b	1535bc
896 annually	1513ab	1409bc
1344 annually	1760b	1747c

^{z}Mean separation, within years, by Duncan's multiple range test at 5%.

Table 15. Effect of fertilizer and lime treatments on pecan leaf Al – Voigt 'Stuart' Grove, Waycross, Ga.

Treatment number	Fertilizer treatment g/cm of circumference N P K	Leaf Al (ppm)^{z} 1967	1968	1970
1	18 – 8 – 15	1914bc	1833a	1575b
2	36 – 16 – 30	1868b	1956a	1631b
3	45 – 16 – 59	1961c	1898a	1639b
4	89 – 16 – 59	1971c	1948a	1658b
5	18 – 0 – 0^{y}	1602a	1461a	1239a
6	89 – 0 – 0^{y}	1930bc	1915a	1474b
	Limestone treatment			
1	No lime	1944b	1929b	1786b
2	Dolomite^{x}	1886ab	1828ab	1413a
3	Calcite^{x}	1793a	1748a	1409a

^{z}Means for fertilizer treatments or limestone treatments with the same letter within years are not significantly different at the 5% level of Duncan's multiple range test.

^{y}Treatments 5 and 6 were identical to 1 and 4, respectively, until 1964.

^{x}Beginning in 1963, 2.24 metric tons/ha was added when soil pH dropped below 6.0.

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Table 16. Parameters significantly correlated with yield in the current season for young 'Desirable' pecan trees.[z]

Variable	Significant correlation coefficients (r)			
	1967	1968	1969	1970
Tree circumference	.34	.35	.32	.41
Phosphorus applied	.32	NS	.22	NS
Leaf Mn	.22	.28	.27	.24
Soil P (15-30 cm level)	NS	−.25	−.23	NS
Color rating	--	.29	.29	.34
Vigor rating	--	.35	.52	.60
Nutlet count, spring	--	--	.48	.57
Leaf Ba	--	--	.41	.22

[z]N = 97-108.

treatments were started and apparently all treatments supplied sufficient nutrients to maintain adequate levels for good growth and yield during the study. Leaf N, P, and K were usually within the suggested normal ranges for these elements, but by the end of the study treatments supplying no P or K were becoming lower in these elements than one or more treatments which supplied some P and K annually. These soils were deeper sands than those in the Kennedy Grove, thus permitting more leaching than the soils in the Kennedy Grove. Studies in both these old groves suggest that fertilizer applications based on leaf analysis is satisfactory.

The young trees in the 'Desirable' Grove were planted on land that had been recently cleared and the ambient soil fertility, except for P, was low compared with the other groves. Fertilizer applied prior to application of treatments was limited to the vicinity of the trunk and transplant hole, thus trees readily responded to N when tree roots grew out of this fertilized area. The soil was sandy and N and K leaching was probably rapid. Also, the water table was high which further limited the area in which the roots could feed. For these young trees yield was still increasing at insignificant levels with the second 56 kg increment of N, and growth increases had stopped with this increment. The low N level for all N treatments in this grove compared with that of the 'Stuart' Grove could be a characteristic of the cultivar. The green color appears less intense in 'Desirable' than in most other cultivars and suggests that nutrient ranges might need to be different for different cultivars. Although yield was not yet affected by K treatments, the low leaf K content and appearance of K deficiency symptoms made it apparent that the K_0 level was too low. When soil test plus applied levels were adjusted to 112 kg/ha annually, however, leaf K was within the suggested ranges used for leaf analysis (5, 45). Additional K caused high leaf K levels and reduced leaf Mg. This complimentary ion effect between K and Mg is well known (41) and was also indicated with pecan data by Sharpe et al. (29).

Excess K not only costs more but may lower quality by increasing the nuts/kg count, decreasing the percentage of nuts in the largest size classification, and decreasing the percentage fancy kernels. It may cause imbalances of other nutrients by increasing the level of Mn, Fe, Al, and Na. Its effect on leaf Al was striking and has apparently not been reported previously. Pecan leaves are extremely high in Al compared with many other crops, and the significance of the K-Al relationship is not known. Interactions of various elements with K have not been extensively studied. Olsen reviewed micronutrient interactions in 1972 but did not list any with K. Zinc-P, Zn-N, Fe-P, Cu-P and other interactions were reported (27), but none of these were evident in our studies.

While interactions among the N-P-K treatments in the 'Desirable' Grove were seldom significant, the rates of application were held low. Sparks (39) has shown that with high rates, extreme imbalances of N and K applications can cause severe deficiency symptoms and tree damage.

These studies did not reveal the optimum pH for pecan trees since the highest yields came from unlimed plots and suggests that pecans withstand low pH well. The soil pH of 5.3 obtained in unlimed plots might not be low enough to cause nutritional problems for pecans since highest yields were obtained from plots that reached pH 4.9 in Hunter and Hammar's studies (20). Johnson and Hagler (24) obtained seedling growth increases by increasing pH from 4.5 to 7.5, but there was no evidence for such a growth relationship for large trees in this study.

Liming with calcite reduced leaf Mg levels and indicates that liming with this source could be detrimental to the tree if Mg were low. Lime induced Zn deficiency is well known (9, 15), but Zn was high in leaves from all lime treatments and was not affected by lime treatments in this study.

These studies also revealed little benefit from P applications and support the work of Alben and Hammar (2) that responses from this element are obtained only when soil levels are extremely low.

Literature Cited

1. Alben, A. O. 1947. Analysis of pecan leaves as an aid in fertility studies. *Proc. Texas Pecan Growers Assoc.* 26:51-58.
2. ______, and H. E. Hammar. 1939. Phosphorus content of some southwestern pecan soils and influence of phosphate fertilizers on pecan foliage. *Soil Sci. Soc. Amer. Proc.* 4:173-176.
3. ______, and ______. 1963. Effect of season and treatment and crop load on the increase in cross sectional area of trunk and on the composition of 'Stuart' pecan leaves. *Proc. Amer. Soc. Hort. Sci.* 82:237-242.
4. ______, and ______. 1964. Soil penetration and uptake of P and K in a 10-year NPK fertilizer experiment with Schley pecan trees. *Soil Sci.* 97:179-182.
5. Amling, H. J. 1965. Alabama pecan leaf analysis service. *Proc. S. E. Pecan Growers Assoc.* 58:25-33.
6. Blackmon, G. H. 1936. Effects of fertilizer on the yield of pecan trees. *Proc. S. E. Pecan Growers Assoc.* 30:19-25.
7. ______, and R. M. Barnette. 1936. A cover crop program for Florida pecan orchards. *Fla. Agr. Expt. Sta. Bul.* 297. 44 p.
8. ______, and R. W. Ruprecht. 1932. Report on pecan fertilizer experiments being conducted by the Florida Agricultural Experiment Station. *Proc. Ga.-Fla. Pecan Growers Assoc.* 26:14-23.
9. Brooks, Orien L. 1964. Yield and growth response of Stuart pecan trees to zinc sulfate and nitrogen. *Ga. Agr. Expt. Sta. Circ. N.S.* 40. 11 p.
10. Crane, H. L. 1931. Some factors affecting premature dropping of pecans. *Nat. Pecan Assoc. Bul.* 30:92-97.
11. ______, and M. B. Hardy. 1934. Interrelations between cultural treatment of pecan trees, the size and degree of filling of nuts, and the composition of kernels. *J. Agr. Res.* 49:643-661.
12. Fowler, E. D. 1931. A report on pecan fertilizers for the southeastern U.S. *Proc. Ga.-Fla. Pecan Growers Assoc.* 25:6-10.
13. ______, J. J. Skinner, and R. W. Ruprecht. 1933. Results of 10 year's fertilizer experiments with pecan on Blanton fine sand and Bladen fine sandy loam. *Nat. Pecan Assoc. Bul.* 32:74-84.
14. Hagler, T. B., and W. A. Johnson. 1955. Relation of nutrient-element content of pecan leaves to the yield of nuts. *Proc. S. E. Pecan Growers Assoc.* 48:77.
15. ______, R. L. Livingston, and W. A. Johnson. 1957. Lime and zinc for pecans. *Proc. S. E. Pecan Growers Assoc.* 50:92-94.
16. Hammar, H. E., and J. H. Hunter. 1948. The time factor in response of pecan trees to fertilizer applications. *Proc. S. E. Pecan Growers Assoc.* 41:36-43.
17. Hardy, M. R., and H. L. Crane. 1932. Can composition of pecan nuts be changed by fertilizer or other cultural treatment? *Proc. Nat. Pecan Assoc.* 31:110-114.
18. Hunter, J. H. 1964. Time of applying nitrogen to pecan trees in sod. *Proc. S. E. Pecan Growers Assoc.* 57:18-22.
19. ______. 1966. Progress report with sprays of nitrate of potash on pecans. *Proc. S. E. Pecan Growers Assoc.* 59:46-50.
20. ______, and Harold Hammar. 1947. The results of applying different fertilizers to the Moore variety of pecan over a 10-year period. *Proc. S. E. Pecan Growers Assoc.* 40:10-32.
21. ______, and ______. 1948. Nutritional deficiencies associated with poor filling of pecan nuts. *Proc. S. E. Pecan Growers Assoc.* 41:16-34.
22. ______, and ______. 1961. Effects of different grades and rates of fertilizer applied to Schley pecan trees as influenced by other factors. *Proc. S. E. Pecan Growers Assoc.* 54:29-41.
23. ______, and R. D. Lewis. 1942. Influence of fertilizer and time of its application on growth, yield, and quality of pecans. *J. Amer. Soc.*

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Agron. 34:175-187.
24. Johnson, W. A., and T. B. Hagler. 1955. Response of pecans to applications of lime and zinc. *Proc. S. E. Pecan Growers Assoc.* 48:78-82.
25. Jones, J. B., and Myron H. Warner. 1969. Analysis of plant ash solutions by spark-emission spectroscopy. *Dev. Appl. Spec.* 7A:152-160.
26. Lepper, Henry A. [Chairman]. 1950. Official methods of analysis of the Association of Agricultural Chemists. 7th Ed. p. 12-13. *Offic. Agr. Chem.*, Washington, D.C. 910 p.
27. Olsen, S. R. 1972. Micronutrient interactions. p. 243-264. *In* J. J. MortVedt, P. M. Giordano, and W. L. Lindsay. Micronutrients in agriculture. Soil Sci. Soc. Amer., Inc., Madison, Wisc.
28. Sharpe, Ralph H., G. H. Blackmon, and Nathan Gammon, Jr. 1950. Progress report of potash and magnesium fertilization of pecans in Florida. *Proc. S. E. Pecan Growers Assoc.* 43:86-97.
29. ______, ______, and ______. 1952. Relation of potash and phosphate fertilization to cold injury of 'Moore' pecans. *Proc. S. E. Pecan Growers Assoc.* 45:81-84.
30. Skinner, J. J. 1921. Fertilizer experiments on pecans conducted by the United States Department of Agriculture. *Proc. Ga.-Fla. Pecan Growers Assoc.* 15:4-11.
31. ______. 1922. Influence of fertilizers on yield, size, and quality of pecans. *Proc. Gu.-Fla. Pecan Growers Assoc.* 16:50-56.
32. ______. 1923. Management and fertilization of pecan soils. *Proc. Nat. Pecan Growers Assoc.* 22:123-133.
33. ______. 1926. Pecan soils and their fertilization. *Nat. Pecan Growers Assoc. Bul.* 25:54-65.
34. ______. 1927. The work of the Bureau of Chemistry and Soils with pecans. The relation of soil fertility and commercial fertilizers to pecan production. *Proc. Nat. Pecan Assoc.* 26:52-65.
35. ______, and C. A. Reed. 1925. Effect of fertilizers and cover crops on growth of pecan trees and the influence of soil conditions on resistance to winter injury. *Proc. Ga.-Fla. Pecan Growers Assoc.* 19:20-33.
36. ______, and R. W. Ruprecht. 1926. Results of fertilizer experiments with pecans in the Jacksonville section. *Proc. Ga.-Fla. Pecan Growers Assoc.* 20:24-32.
37. Smith, C. L., O. W. Harris, and H. E. Hammar. 1960. Comparative effects of clean cultivation and sod on tree growth, yield, nut quality and leaf composition of pecan. *Proc. S. E. Pecan Growers Assoc.* 53:15-16.
38. Sparks, Darrell. 1968. Some effects of nitrogen on young pecan trees. *Proc. S. E. Pecan Growers Assoc.* 61:93-102.
39. ______. 1972. Deficiency and toxicity symptoms of nitrogen and potassium in the 'Desirable' pecan. *Proc. Ga. Pecan Growers Assoc.* 3:27-30.
40. Taylor, R. W. 1930. Influence of fertilizer treatments on yield and quality of pecans. *Nat. Pecan Assoc. Bul.* 29:18-22.
41. Tisdale, S. L., and Werner L. Nelson. 1966. Soil fertility and fertilizer. 2nd Ed. The Macmillan Co., New York, N.Y. 644 p.
42. Upson, J. R., and Darrell Sparks. 1967. Growth response of one-year-old 'Stuart' pecan seedlings in sand culture to various levels of potassium. *Proc. S. E. Pecan Growers Assoc.* 60:89-99.
43. Ware, L. M. 1961. Why pecans demand liberal fertilization. *Better Crops with Plant Food.* 45(4):28-31.
44. Warner, Myron H., and J. B. Jones. 1970. A rapid method for nitrogen determination in plant tissue. *Soil Sci. and Plant Anal.* 1:109-114.
45. Worley, Ray E. 1971. Pecan leaf analysis service summary, 1969. *Ga. Agr. Expt. Sta. Res. Rep.* 110. 30 p.
46. ______, S. A. Harmon, and R. L. Carter. 1972. Effect of zinc sources and methods of application on yield and leaf mineral concentration of pecan, *Carya illinoensis*, Koch. *J. Amer. Soc. Hort. Sci.* 97:364-369.

Effect of Repeated N, P, K, and Lime Applications on Soil pH, P, and K Under Old and Young Pecan Trees[1]

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Abstract. Concentration of pecan roots in the 15-45 cm layer of soil and lower soil pH, P, and K in the 15-30 cm layer than in adjacent layers indicate that pecan trees are feeding primarily in this zone. Fertilization with N-containing complete fertilizers or NH_4NO_3 reduced soil pH gradually, and continued annual application gradually affected deeper soil layers. Phosphorus and K applications affected soil pH very little.

Continued annual applications of P gradually built up residual soil P (measured one year later) to high levels at all layers sampled for old trees over a 10-year period. When P applications were based on topsoil P levels, subsoil P level was not affected over a 5-year period.

Applications of K usually increased residual soil K, but rate effects were slow to appear in old trees and were often erratic. Rates of K were readily reflected in residual soil K levels at depths to 70 cm when rates were based on topsoil K level.

Conflicting reports on the response of pecan to fertilization suggest that the soil concn of fertilizer nutrients determines to a great extent the response that a tree will give to added fertilizer. Since pecan tree roots occupy a tremendous volume of soil (8), more information is needed concerning the effect that different fertilization practices have on soil pH, P, and K throughout the soil profile. Since leaf analysis and soil analysis are seldom correlated (10), the trees might be feeding in an area below that normally sampled. A comparison of P and K concn at different depths in the soil profile should give an indication of the movement of these nutrients in soils under pecan trees.

Materials and Methods

Three groves were used. 1) The Kennedy Grove of 'Stuart' trees approximately 40 years old was spaced 21 x 21 m in Tifton loamy sand. Fertilizer treatments, which began in 1962, were 0, 448 kg/ha (400 lb/acre) biennially and 448, 896, and 1344 kg/ha (400, 800, and 1200 lb/acre) annually of commercially mixed 10-4.4-8.3 (N-P-K). Nine single tree replications were used in a completely randomized design. The trees were fertilized prior to the initiation of treatments, and their appearance was good. Dolomite at 2.2 metric T/ha was applied to all plots in 1963. Twelve 2.5 x 15 cm soil plugs were taken on July 31, 1962, and thereafter, at the end of each growing season in January or February just prior to fertilizer application. For example, data for the 1963 season were from soil sampled in January 1964. In 1968, 1970, and 1971 soil was sampled at 15-cm intervals to 75 cm at 4 locations under each

[1]Received for publication December 21, 1972.
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