Time of Nitrogen Application and Phosphorus Effects on Growth, Yield, and Fruit Quality of Pecan

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Abstract. March vs. October N applications in factorial combination with two P rates were evaluated on two pecan [*Carya illinoensis* (Wangenh.) C. Koch] cultivars. Leaf N concentrations were not affected by N application time. However, yield of 'Hayes' was increased during 4 of 7 years and cumulative yield was increased 37% when N was applied during October compared to March. Yield of 'Patrick' and individual nut weight and kernel percentage of 'Hayes' and 'Patrick' were not affected by N application time. Phosphorus application increased leaf P concentration 5 of 7 years during the study. Shoot growth, yield, individual nut weight, and kernel percentage were not affected by P application.

Nitrogen is usually applied during February or March in Oklahoma pecan orchards. This application time is commonly used because few other activities during this period compete for the growers attention, and, historically, N applications during February or March have visibly benefitted the orchard with no observable adverse affects. Also, growers have targeted this period because ground covers are inactive, which may minimize competition for applied N. However, in many areas where pecans are native, late winter and spring flooding frequently prevents timely N application or may cause substantial loss of applied N. Therefore, alternative application times may be beneficial.

Although late winter or early spring are traditional times to apply N to fruit and nut trees, research on apple (*Malus domestica* Borkh.) and pear (*Pyrus calleryana* L.) indicates other application times are acceptable or, in some cases, superior. Fall N applications accelerated flower bud development and extended stigma receptivity and ovule longevity compared to spring N applications (Hill-Cottingham, 1968; Williams, 1965). Apple fruit set was increased when N was applied during the fall rather than the spring (Hill-Cottingham, 1968; Hill-Cottingham and Williams, 1967). However, others have reported no consistent relationship between application time and apple yield (Goode and Higgs, 1977). Taylor et al. (1975) reported N applied to pear in the spring was assimilated inefficiently compared to fall-applied N. They hypothesized that insufficient available carbo-

hydrates in the spring prevented efficient N assimilation.

In pecan, Gammon and Sharpe (1955) reported growth was maximum when trees were fertilized 1 Feb. or earlier. They recommended fertilization during winter while the grass was dormant and offered the least competition. Hunter and Lewis (1942) evaluated several fertilizer application times on pecan. Application time did not affect yield, but nut quality was reduced when part of the fertilizer was applied during April or June. They speculated that additional growth stimulated by these application times competed with fruit development, thus reducing quality.

The optimum leaf concentration range for P in pecan is poorly defined. Several early studies failed to clearly determine the optimum P concentration range for growth, production, and fruit quality, primarily due to difficulties in obtaining substantial P absorption from soil applications (Alben and Hammar, 1964; Worley, 1974, 1977; Worley et al., 1974). To our knowledge, there are no reports of improved pecan yield, but two studies have reported P application improved kernel percentage (Hunter, 1951; Sparks, 1988). Most scientists working with pecan are using 0.12% as the minimum acceptable leaf P concentration and from 0.19% to 0.3% as the maximum acceptable leaf P concentration (Smith, 1991). However, recent evidence supports a higher minimum acceptable P concentration. Smith and Cotten (1985) reported that cold damage of 'Western' pecan decreased as leaf P concentrations increased from 0.11% to 0.17%. Sparks (1986, 1988), based on greenhouse and field tests, suggested the minimum sufficiency level of P (0.12%) for pecan was too low. He found that maximum vegetative growth of greenhouse-grown pecan seedlings occurred when leaf P concentrations were 0.19% to 0.22%. His field studies with adult trees showed that greatest fruit growth and minimum leaf scorch and defoliation occurred when leaf P was >0.14% and 0.16%, respectively.

This study evaluated the time of N application on selected performance characteristics of pecan. Additionally, applications of large quantities of P were evaluated to determine if increased leaf P concentrations could be achieved, and correlated with improved growth, yield, or fruit quality.

Materials and Methods

Our study, located at the Pecan Research Station near Sparks, Okla., was initiated in 1985 on 35-year-old 'Patrick' and 'Hayes' pecan trees. Trees were thinned to 22/ha in 1984, leaving wide aisles for interplanting young pecan trees. This wide spacing served as a border between treatments. The soil was a port silt loam (fine-silty, mixed, thermic; Cumulic Haplustoll; Mollisols). Management included a closely mowed grass sod with 2-m-wide, weed-free strips on each side of the tree, and pesticide applications recommended for commercial orchards in Oklahoma (Taylor et al., 1992; von Broembsen et al., 1992). Trees were not irrigated. The average budbreak date at this location is 15 Apr., and trees defoliate about 12 Nov.

Treatments were spring vs. fall N application in factorial combination with two P rates. Nitrogen (NH_4NO_3) was either applied the second week of March or the first week of October each year from 1985 through 1992 at 112 kg N/ha. Nitrogen was uniformly broadcast from the trunk to the drip line. Phosphorus (triple superphosphate) was applied, with a drop-type spreader, during Mar. 1986 and again in May 1989 at 244 kg P/ha each application, from the trunk to 4 m beyond the drip line. Phosphorus and N applications were not incorporated. Each treatment combination was replicated four times. Sources of variation for the experimental design are shown in Tables 1 and 2. Data were tested using analysis of variance with Fisher's protected LSD.

Leaf samples were collected each year during July, using the middle pair of leaflets from the middle leaf on current-season's growth as the index tissue. Leaf samples were washed in distilled water, followed by a detergent wash (P-free detergent) then two distilled deionized water rinses. Samples were then dried at 80C, ground to pass a 20-mesh (850- μm) screen, and stored in airtight glass jars until analysis. Nitrogen was determined using the macro-Kjeldahl method (Horowitz, 1980), and P was determined colorimetrically (Olsen and Sommers, 1982).

Soil samples were collected during Oct. 1989 and 1991 for pH and P analysis. Three samples were taken within the drip line of each tree at soil depths of 0 to 5 cm, 5 to 15 cm, and 15 to 30 cm in 1989, and the same depths plus 30 to 45 cm in 1991. The three samples per tree were composited for each depth, mixed, and an aliquot taken for analysis. Soil pH was determined in a 1 water : 1 soil ratio and P extracted by Bray 1 solution with a 20 solution : 1 soil ratio and quantitated by the ascorbic acid color development method of Olsen and Sommers (1982).

Shoot length was measured and the num-

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Table 1. Sources of variation for leaf N and leaf P concentrations.

Source	df	Sum of squares	
		Leaf N	Leaf P
Cultivar (C)	1	1.6303**	0.0018**
Block	3	0.3312**	0.0002
Error A	3	0.0768	0.00011
Phosphorus (P)	1	0.000004	0.0025*
Error B	3	0.04168	0.00083
C × P	1	0.0004	0.00008
Error C	3	0.1989	0.00034
Nitrogen (N)	1	0.0372	0.0015***
C × N	1	0.0007	0.0001
P × N	1	0.0022	0.0001
C × P × N	1	0.0299	0.000001
Error D	12	0.3009	0.0007
Year (Y)	6	2.9624***	0.01340***
Y × C	6	0.1380	0.0013*
Y × P	6	0.0405	0.0011*
Y × N	6	0.1324	0.0005
Y × C × P	6	0.1304	0.0003
Y × C × N	6	0.0541	0.0011
Y × P × N	6	0.0478	0.0002
Y × C × P × N	6	0.2357	0.0006
Error E	144	3.3718	0.0123

*, **, ***Significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 2. Sources of variation for shoot length, number of current-season shoots per 1-year-old shoot, yield, kernel percentage, and nut weight.

Source	df	Sum of squares				
		Shoot length	Shoots/ 1-year-old branch	Yield	Kernel percentage	Nut wt
Cultivar (C)	1	494.57**	0.43	2009.78**	443.53**	16.73**
Block	3	9.05	0.34	246.26	40.30	7.42*
Error A	3	27.78	0.40	170.80	21.57	0.37
Phosphorus (P)	1	5.45*	0.37*	12.98	1.61	0.11
Error B	3	1.30	0.03	31.39	2.55	0.41
C × P	1	0.02	0.28	1.64	0.73	0.13
Error C	3	8.04	0.31	49.99	14.12	0.016
Nitrogen (N)	1	17.56*	0.07	129.25	3.63	0.06
C × N	1	36.09**	0.16	269.07*	0.26	0.001
P × N	1	1.68	0.01	26.11	0.68	0.001
C × P × N	1	5.38	0.05	0.01	2.40	0.10
Error D	12	27.71	1.55	366.83	38.22	2.34
Year (Y)	5	88.70***	3.88***	7161.67***	1869.56***	19.96***
Y × C	5	8.56	1.02*	1152.86***	92.86***	3.36**
Y × P	5	16.69	0.11	33.58	17.62	0.30
Y × N	5	26.28	0.25	133.86	0.49	8.53
Y × C × P	5	3.36	0.22	33.31	2.18	0.34
Y × C × N	5	28.09	0.47	65.83	9.96	0.24
Y × P × N	5	6.84	0.17	5.81	8.39	0.73
Y × C × P × N	5	15.19	0.63	69.82	17.58	1.17
Error E	120	349.08	10.31	1491.89	357.55	22.93

*, **, ***Significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

ber of current-season shoots per 1-year-old branch was counted yearly during dormancy. Thirty 1-year-old branches located at the canopy periphery 6 to 7 m above ground were selected and the longest current-season shoot measured and the number of current-season shoots per branch counted on each tree.

Trees were harvested individually during November, nuts processed through a cleaner and weighed. Duplicate 10-nut samples, collected before cleaning, were weighed and cracked to determine weight per nut and kernel percentage.

Temperatures dropped to -12°C during 2 and 3 Nov. 1991. No freezing temperatures occurred before this sudden decrease, and several pecan cultivars were severely damaged. Four branches were collected from each tree during December, and cold injury was rated on 1-, 2-, and 3-year-old wood, where 1

= no injury, 2 = slightly discolored discontinuous areas in the cambium region, 3 = brown streaking in the cambium region, 4 = most of the cambium region dead with only small areas of live tissue, and 5 = all tissue in the cambium region dead.

Results

Leaf N concentrations were not affected by the N application time; however, there was significant variation in leaf N concentration between years (Table 1). Leaf N ranged from 2.21% to 2.56%, with leaf N during most years $\geq 2.5\%$. The low N concentrations correspond to years with high rainfall and occasional orchard flooding. Similarly, Smith and Bourne (1989) reported that flooding or water-saturated soils reduced leaf N concentrations. The leaf N concentration of 'Patrick' (2.56%) was

greater than that of 'Hayes' (2.38%). Phosphorus application did not affect leaf N concentration.

Soil P concentrations, sampled in 1989 and 1991, indicated that P application increased P concentrations from the surface through the 30-cm depth by 1989 and the 45-cm depth by 1991 compared to the unfertilized treatment (Fig. 1). Phosphorus concentrations decreased as soil depth increased in fertilized and unfertilized plots, but the decline in P with sample depth was more dramatic in the P-fertilized plots. However, these data indicate that P had moved into the soil profile where large concentrations of roots were observed during soil sampling. Thus, absorption of P by the tree likely would not be limited by lack of P movement into areas of active roots. Soil pH was not significantly affected by N or P treatment or by soil depth (data not shown); soil pH averaged ≈ 6.3 in 1989 and 1991.

There were significant year $\times$ cultivar and year $\times$ P treatment interactions affecting leaf P concentration (Table 1). The lowest leaf P concentration during the study was 0.122% during 1992 on 'Patrick' and the highest was 0.148% in 1988, also on 'Patrick'. These concentrations are within normal ranges suggested for Oklahoma (Smith, 1991). Leaf P concentrations in 'Patrick' were higher than those of 'Hayes' during 4 years, and there were no significant differences in leaf P between cultivars the other 3 years (data not shown). Phosphorus application increased leaf P in 5 of 7 years; however, differences in leaf P between treatments were small ($<0.012\%$). Leaf P concentrations were slightly higher when N was applied during the spring (0.139%) than the fall (0.134%).

There was a significant cultivar $\times$ N application time interaction affecting shoot length (Table 2). Shoot growth of 'Hayes' (7.7 cm) was not affected by the N application time, but shoots of 'Patrick' were longer when fertilized in the spring (11.7 cm) than the fall (10.2 cm). We saw no new growth flushes during the fall as a result of the October N application. Phosphorus applications increased shoot length (9.5 cm) compared to those not receiving P (9.1 cm).

A significant interaction was detected for the number of current-season shoots produced from each 1-year-old branch (1YOB) (Table 2). 'Hayes' (1.91 shoots/1YOB) produced more new shoots/1YOB than 'Patrick' (1.82 shoots/1YOB) during all years, except 1988 and 1991. Phosphorus application slightly increased the number of current-season shoots per 1YOB (1.91 vs. 1.82 shoots/1YOB). Nitrogen application time did not affect the number of new shoots/1YOB (data not shown).

There were significant interactions between year with cultivar and cultivar with N affecting yield (Table 2). Yield of 'Hayes' (13.0 kg/tree, 6-year average) was higher than that of 'Patrick' (6.5 kg/tree) during 5 of the 6 years (data not shown). Nitrogen application time did not affect yield of 'Patrick'; however, yield of 'Hayes' was 10.9 kg/tree when fertilized during the spring and 14.9 kg/tree when fertilized during the fall. Cumulative yield of 'Hayes'

Fig. 1. Soil phosphorus distribution in 1989 and 1991 in fertilized and unfertilized plots following application of 244 kg P/ha during Mar. 1986 and May 1989. Means within each sample depth and year were significantly different, $P \leq 0.05$.

was 37% higher when N was applied during October compared to March.

A significant year $\times$ cultivar interaction was identified for both kernel percentage and nut weight (Table 2). 'Hayes' (4.25 g/nut; 54.8% kernel) produced a heavier nut with a lower kernel percentage than 'Patrick' (3.66 g/nut; 57.8% kernel) during most years. Neither N application time nor addition of P affected kernel percentage or nut weight (data not shown).

The amount of cold damage sustained by either cultivar was not affected by N application time or P application (data not shown). Cold damage ratings were 1.0 and 1.2 for 'Patrick' and 'Hayes', respectively. These ratings indicate that neither cultivar was appreciably damaged by the fall freeze, even though several other cultivars were severely damaged at this site (Smith et al., 1993).

Discussion

'Patrick' has a low yield potential relative to most commercial cultivars. In this study, yield of 'Patrick' was about half that of 'Hayes'. Low yield of 'Patrick' compared to 'Hayes' may cause 'Patrick' to be insensitive to N application time. Nitrogen transport to the crop would be greater in 'Hayes' than in 'Patrick' and could create a late-season N deficiency in 'Hayes'. Thus, 'Hayes' would benefit from fall N application and 'Patrick' would not. Alternatively, leaf N concentrations, measured during July, were higher in 'Patrick' than in 'Hayes', although N application rates were the same. If N concentrations in 'Hayes' were low enough to inhibit flower initiation, and N concentrations in 'Patrick' were adequate for initiation, then fall applications would benefit only 'Hayes'. However, earlier research in Oklahoma with 'Western' suggested that 2.3% leaf N during July was adequate (Smith et al., 1985). In all years, except in 1990 and 1992, when excess water

reduced leaf N concentrations, leaf N concentrations of 'Hayes' were $>2.4\%$. This result suggests that either the minimum leaf N sufficiency level in July established for pecan in Oklahoma is inadequate, or 'Hayes' responded to fall N application even though July N concentrations were adequate.

Phosphorus applications increased leaf P concentrations of 'Hayes' and 'Patrick' during some years; however, the increases were small and of doubtful physiological significance. Lack of P absorption was not caused by restricted P movement in the soil; soil P concentrations increased in the root zone. Phosphorus applications did not improve yield or fruit quality in this study. Similarly, others have reported little response in pecan from applied P (Alben and Hammar, 1964; Worley, 1974, 1977; Worley et al., 1974). To our knowledge, no studies on pecan have reported P application increased yield, but two studies found P application improved kernel yield (Hunter, 1951; Sparks, 1988).

This study indicates that October N applications were beneficial for 'Hayes' but not for 'Patrick'. Cultivars may respond differently to March vs. October N applications; however, no adverse effects of fall N applications were found. Thus, growers can choose fall N applications to avoid problems with unpredictable spring weather, and, in some cases, yield may be improved.

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