A Long-term Comparison of Broadcast Application versus Drip Fertigation of Nitrogen for Mature Pecan Trees

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Summary. No reduction in yield and quality of pecan nuts or leaf mineral nutrient concentration occurred when 100 lb/acre of N was applied through a drip-irrigation system compared with 200 lb/acre applied either all broadcast or half broadcast and half fertigated. Yield of 'Stuart', percentage kernel of 'Schley', and nut size of both cultivars were increased by irrigation or irrigation and fertigation. The 100 lb/acre N-all-fertigated treatment resulted in less soil pH reduction and less loss of K, Ca, and Mg from soil underneath the tree canopy than broadcast treatments. No evidence of excessive soil pH reduction in the wetted zone of fertigated trees was noticed. Calcium and Mg were higher within than outside the wetted zone.

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Addition of N fertilizer periodically throughout the growing season in irrigation water provides the best means of fertilization without injury to plants (Stanford and Legg, 1984). Fertigation has proven to be an economical method of applying nutrients to several fruit species (Klein et al., 1989; Smith et al., 1979). Compaction is a serious problem in many pecan [*Carya illinoensis* (Wangenh.) C. Koch] orchards (Trowse, 1978). If feasible and efficient, fertigation could save pecan growers millions of dollars through reduced compaction from the fertilizer application truck, reduced application costs, and more efficient use of applied fertilizer through reduced leaching losses. The elimination of one application of 100 lb/acre of N on the 150,000 acres of pecans in Georgia alone would amount to a saving of more than \$4 million just in material costs. Less applied N also means less pollution of surface and ground water. Trials on young pecan trees indicate that fertigation through the drip system is feasible and more efficient than conventional methods of application (Aitken, 1986). This paper reports results of a 10-year study on feasibility of applying N to old pecan trees via drip irrigation. A similar study on peaches at Fort Valley, Ga. (Edwards et al., 1982), reported a substantial soil pH reduction in the wetted zone from fertigated N. Our study also was designed to determine if soil pH reduction by fertigation was a problem with pecan.

Materials and methods

This study was originally a part of a larger entomological study on an old (estimated >50-year-old) pecan orchard on President Jimmy Carter's family estate near Plains, Ga. The 35-acre orchard consists mainly of 'Stuart' and 'Schley' trees growing on Red Bay and Greenville soil. This location is within 50 miles of Albany, Ga., and within the area and on soil types that produce about one-third of the world's pecans. The orchard had been abandoned, but was brought back into production in the late 1970s. It is typical of many older pecan orchards that produce most of the world's crop. The statistical design was a split-plot with three replications. Main plots consisted of eight insect control treatments, and subplots consisted of four

irrigation-fertilizer treatments. Each plot of up to five trees contained one or more 'Stuart' and 'Schley' trees. The irrigation-fertilizer treatments were replicated 24 times. This paper concerns only the results of the irrigation-fertilizer subplot treatments. The whole-plot treatments were discontinued in 1982, and results of whole-plot treatments were reported previously (Dutcher et al., 1984). Irrigation-fertilizer treatments were as follows.

- 1) No irrigation-200 lb/acre (224 kg·ha⁻¹) N with all the N surface-broadcast. One-half of the N was applied about 1 Apr. and the remainder about 1 June.
- 2) Drip irrigation with 200 lb/acre N broadcast as for (1).
- 3) Drip irrigation with 100 lb/acre (112 kg·ha⁻¹) N broadcast as for (1) plus 25 lb/acre (28 kg·ha⁻¹) N injected into the irrigation water (fertigated) about 1 Apr., 1 May, 1 June, and 1 July for a total of 100 lb/acre N fertigated.
- 4) No broadcast N with 100 lb/acre N fertigated as for (3).

All the broadcast N was from ammonium nitrate. A line of emitters

was placed within the herbicide strip on two sides of each tree and two 2-gal/h emitters were spaced about 4 feet apart on each side of each tree on each line for a total of eight emitters per tree. When fertigating, the valves for the irrigation lines for the non-fertigated but irrigated trees were turned off. All irrigated trees received the same amount of irrigation water except for the four times each year when fertigation occurred. The irrigation system was operated 1 h (or more, usually overnight) after each fertigation to flush the system and distribute the N through the wetted zone. Otherwise, irrigation was applied 12 h/day beginning about 3 days after each rain of 1 inch during the growing season, or if there was visual indication of need. This method approximates recommended irrigation practices for growers in the area.

In 1980, the injected N source was prilled calcium nitrate. This material was difficult to inject due to the clay coating of the prills. Thereafter, liquid Uran (16% N from urea, 16% N from ammonium nitrate) was the N source. The injection rate was 25 gal of the concentrated solution/h after the first year. Additional nutrients and lime

were added uniformly to all trees each spring if leaf or soil analysis indicated need. Calcium hydroxide at 2.3 lb/emitter was applied within 1 foot (30 cm) of emitters in fertigated plots on 5 May 1981 to neutralize the anticipated acidity in the wetted zone caused by the injected N.

Yield and quality data were taken for each tree and presented separately for 'Stuart' and 'Schley'. A 50-nut sample was taken from each tree at harvest, sized by categories separated by 1/16 inch (0.16 cm) of diameter, and then cracked. Kernels were graded into fancy, standard, and amber grades and percentage of each size, kernel grade, and total percentage edible kernel was calculated. Fancy kernels were plump, well-filled kernels of the brightest color. Standard kernels were similar, but darker. Amber kernels were darker than standard kernels and/or had edible kernels with defects.

Leaf samples were taken from each plot between the second week in July through the first week of August and soil samples were taken in winter each year. The samples were analyzed using atomic absorption procedures for cations, colorimetric procedures for P, and Kjeldahl for N (Worley, 1974;

Table 1. Yield and quality of 'Schley' pecans when not irrigated, drip-irrigated (DI), and fertigated (F) with N.

N applied													
Broadcast (lb/acre)	F	DI	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Mean
<i>Yield (lb/tree)^a</i>													
200	0	No	64 a ^y	32 b	18 a	2 a	46 a	29 a	20 a	44 a	41 b	28 a	32 a
200	0	Yes	65 ab	26 ab	12 a	2 a	38 a	21 a	27 a	78 b	29 ab	25 a	33 a
100	100	Yes	78 c	22 ab	20 a	7 a	40 a	26 a	28 a	76 b	32 ab	24 a	36 a
0	100	Yes	75 bc	19 a	14 a	2 a	37 a	24 a	23 a	73 b	25 a	28 a	32 a
N			40	38	40	40	39	32	40	40	27	40	376
LSD (0.05)			10.0	10.3	10.0	10.0	10.2	11.2	10.0	10.0	12.2	10.0	6.0
<i>Percent kernel^b</i>													
200		No	57 a	51 a	56 a	51 a	50 a	53 a	56 a	50 a	56 b	52 a	53 a
200	0	Yes	58 a	51 a	54 a	50 a	53 b	53 a	55 a	58 c	53 a	53 a	54 a
100	100	Yes	58 a	52 a	55 a	50 a	52 ab	54 a	55 a	56 b	55 ab	52 a	54 a
0	100	Yes	58 a	52 a	55 a	53 a	52 ab	54 a	55 a	55 b	55 ab	54 a	54 a
N			36	24	35	3	37	26	29	38	24	36	288
LSD (0.05)			2.1	2.6	2.2	7.3	2.1	2.5	2.4	2.1	2.6	2.1	1.2
<i>Nuts/lb^y</i>													
200	0	No	107 b	93 b	76 a	68 a	85 b	76 b	93 c	82 b	72 b	84 a	86 b
200	0	Yes	70 a	69 a	72 a	60 a	78 a	71 a	80 a	73 a	66 a	82 a	74 a
100	100	Yes	74 a	73 a	73 a	69 a	82 ab	71 a	86 b	73 a	69 ab	81 a	76 a
0	100	Yes	70 a	72 a	72 a	62 a	78 a	73 ab	77 a	73 a	67 ab	83 a	74 a
N			39	72	36	3	38	32	29	39	24	36	306
LSD (0.05)			4.0	4.5	4.1	14.3	4.0	4.4	4.6	4.0	5.1	4.1	5.2

^aFertilizer × year interaction significant at 50.05.

^yMean separation for variable within columns by Duncan's NMRT (P = 0.05).

Worley et al., 1974). Additional soil samples were taken within 1 to 2 feet of each emitter to determine the effect of fertigation on soil in the wetted zone.

The statistical design used for analysis of the data was a split-plot in time where replications (replications + whole plot insecticide treatments) and irrigation-fertilizer treatments were the main plots, multiple trees receiving the same treatment in the same replication were the sampling error, and yearly measurements were the subplots (Steel and Torrie, 1960). Because time was not randomized, replication by time was used as the source of error for years. To test irrigation-fertilizer treatment main effects, the greater of either replication by treatment or treatment by year was used as the source of error (Steel and Torrie, 1960). Due to missing plots because trees died or did not produce yield, least-square means were not available.

Results and discussion

Some of the insect control treatments reduced yield; thus, irrigation-fertilizer treatment yields were lower than if they had received the best insect control during the first 3 years of the

study. Yield varied greatly from year to year due to the irregular bearing nature of pecans (Wood et al., 1991). Yield from the fertigated plots receiving the low N rate was as good as those receiving twice the N rate, either broadcast or part injected through the drip system (Tables 1 and 2). Increases in yield from irrigation or irrigation plus fertigation were apparent in 1980 and 1987 for 'Schley' and in 1980, 1981, 1984, 1986, and 1987 for 'Stuart' and for the 10-year average for 'Stuart'. 'Stuart' yields were almost doubled by irrigation alone or by fertigation in 1980 and 1987, but were not affected by treatments in 4 of the 10 years. Irregular bearing is probably responsible for the small increase in yield for the nonirrigated plots over the other treatments for 'Schley' in 1981 and 'Stuart' in 1982. The relatively high yield for nonirrigated 'Stuart' trees in 1982 followed 2 years of relatively low yield. Also, the relatively high yield of nonirrigated 'Schley' in 1981 followed a relatively low yield in 1980. Note also that there is not a clear-cut on-off year sequence.

Kernel quality was not affected consistently by treatments over the years (nut diameter and kernel grade data not shown in tables). Both kernel

quality and nut size were as good or better for the low-N-all-fertigated treatment as for the other treatments (Tables 1 and 2). 'Schley' percentage kernel was reduced by three percentage points in 1984 and eight percentage points in 1987 when irrigation was withheld (Table 1); however, percentage kernel for 'Stuart' was not affected by treatments in any year except 1984, when withholding water reduced percentage kernel below the half-fertigated treatment (Table 2). Withholding irrigation increased percentage fancy and reduced percentage standard kernels of 'Schley' in 1980, but not in other years (data not shown). The most consistent quality difference was in nut size as shown by nuts/lb count and volume/nut (Tables 1 and 2). Nonirrigated trees usually produced smaller nuts (>nuts/lb count) than the irrigated trees.

Other experiments have indicated that a leaf N concentration of 2.75% or greater is sufficient for optimum tree growth, nut yield, and nut quality (Worley, 1985, 1990). Leaf concentrations were 2.56% in all years and >2.75% for all treatments in 6 of 9 years (Table 3). Leaf N was above 3.00% for all treatments in 1988. Differences in leaf N, though sometimes

Table 2.. Yield and quality of 'Stuart' pecans when not irrigated, drip irrigated (DI), and fertigated (F).

N applied													
Broadcast (lb/acre)	F	DI	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Mean
<i>Yield (lb/tree)^a</i>													
200	0	No	42 a ^y	64 a	35 b	25 a	86 a	39 a	37 a	56 a	114 a	35 a	52 a
200	0	Yes	59 b	82 b	17 a	32 a	103 b	35 a	48 ab	103 b	96 a	48 a	62 b
100	100	Yes	62 b	75 ab	21 ab	32 a	112 b	38 a	62 b	110 b	108 a	47 a	66 b
0	100	Yes	66 b	81 b	15 a	32 a	111 b	35 a	57 b	103 b	104 a	44 a	64 b
N			39	39	39	39	38	34	39	39	28	38	372
LSD (0.05)			14.8	14.8	14.8	14.8	15.0	15.8	14.8	14.8	17.4	15.0	9.0
<i>Percent kernel^b</i>													
200	0	No	47 a	44 a	50 a	43 a	43 a	44 a	44 a	43 a	48 a	45 a	45 a
200	0	Yes	46 a	44 a	50 a	42 a	44 ab	45 a	41 a	44 a	47 a	45 a	45 a
100	100	Yes	47 a	43 a	50 a	44 a	45 b	44 a	43 a	45 a	47 a	45 a	45 a
0	100	Yes	47 a	44 a	49 a	44 a	45 ab	46 a	42 a	50 ab	49 a	46 a	46 a
N			39	30	34	19	37	30	32	37	28	37	318
LSD (0.05)			2.7	2.9	2.7	3.7	2.6	2.9	2.8	2.6	3.0	2.6	1.5
<i>Nuts/lb^b</i>													
200	0	No	78 c	81 c	66 a	62 c	62 b	63 b	94 b	69 b	70 b	65 b	71 b
200	0	Yes	58 a	62 b	65 a	57 ab	57 a	60 a	72 a	63 a	61 a	63 ab	62 a
100	100	Yes	62 b	61 ab	65 a	60 bc	59 ab	60 ab	73 a	65 a	62 a	63 ab	63 a
0	100	Yes	59 a	58 a	67 a	55 a	58 a	59 a	70 a	63 a	60 a	62 a	61 a
N			35	36	34	20	37	34	32	38	28	37	331
LSD (0.05)			3.2	3.2	3.3	4.3	3.1	3.3	3.4	3.1	3.6	3.1	3.7

^aMean separation for variable within columns by Duncan's NMRT ($P = 0.05$).

^bFertilizer $\times$ year interaction: yield ($P < 0.01$), percent kernel ($P > 0.10$), nuts/lb ($P < 0.01$).

Table 3. Leaf N of pecan trees when not irrigated, drip-irrigated (DI), and fertigated (F).

N applied												
Broadcast (lb/acre)	F	DI	1981	1982	1983	1984	1985	1986	1987	1988	1989	Mean
200	0	No	2.85 a ^z	2.68 a	3.09 a	2.91 a	2.62 a	2.67 a	2.89 a	3.11 a	2.99 a	2.87 a
200	0	Yes	2.89 a	2.67 a	3.10 a	2.93 a	2.61 a	2.71 a	2.86 ab	3.12 a	2.93 ab	2.87 a
100	100	Yes	2.91 a	2.69 a	3.01 b	2.91 a	2.68 a	2.69 a	2.81 b	3.10 a	2.88 b	2.85 a
0	100	Yes	2.89 a	2.56 b	3.00 b	2.90 a	2.63 a	2.68 a	2.85 ab	3.09 a	2.90 b	2.83 a

LSD (0.05) = 0.067, 23<N<24 (yearly); LSD (0.05) = 0.041, N = 214 (overall)

^zMean separation for variable within columns by Duncan's NMRT (P = 0.05).

Table 4. Leaf mineral concentrations with N applications by broadcast or fertigation (means of 9 years).

Broadcast	Fertigation	P (lb/acre)	K (lb/acre)	Ca (lb/acre)	Mg (lb/acre)	Fe ($\mu\text{g}\cdot\text{g}^{-1}$)	Zn ($\mu\text{g}\cdot\text{g}^{-1}$)	Mn ($\mu\text{g}\cdot\text{g}^{-1}$)	Cu ($\mu\text{g}\cdot\text{g}^{-1}$)
200	0	0.127 a	0.84 b	1.46 a	0.39 a	62 b	89 a	268 ab	9.3 a
200	0	0.128 a	0.80 ab	1.47 a	0.41 b	60 ab	99 a	270 ab	10.0 c
100	100	0.128 a	0.82 ab	1.47 a	0.39 a	59 a	97 a	276 b	9.6 b
0	100	0.131 b	0.79 a	1.48 a	0.41 b	59 a	96 a	263 a	10.0 c
Interaction									
Fertilizer $\times$ year		NS	**	NS	*	*	NS	*	**
LSD (0.05), N = 214		0.0024	0.041	0.060	0.019	2.73	11.0	11.8	0.34

^zMeans separated within columns by Duncan's NMRT.NS, *, ** Nonsignificant or significant at P $\leq$ 0.05 or 0.01, respectively.

Table 5. Soil analysis for random samples taken underneath trees outside of wetted zone (mean of 6 years).

N applied		Drip irrigation	0-6 inches						6-12 inches			
Broadcast (lb/acre)	Fertigation (lb/acre)		Soil pH	Soil P (lb/acre)	Soil K (lb/acre)	Soil Ca (lb/acre)	Soil Mg (lb/acre)	Soil pH	Soil P (lb/acre)	Soil K (lb/acre)	Soil Ca (lb/acre)	Soil Mg (lb/acre)
200	0	No	5.0 a ^z	89 a	152 a	1163 a	254 a	4.7 a	32 a	92 a	415 a	91 a
200	0	Yes	4.9 a	79 a	163 ab	1128 a	263 a	4.7 a	29 a	104 ab	464 ab	109 a
100	100	Yes	5.1 a	84 a	174 b	1250 a	267 a	4.8 b	33 a	110 b	544 b	114 a
0	100	Yes	5.4 b	86 a	201 c	1524 b	335 b	5.0 c	28 a	125 c	678 c	151 b
LSD (0.05), N=143			0.17	9.6	19.4	234	41.0	0.11	5.9	14.7	98.7	25.3
Interaction												
Fertilizer × year			**	*	NS	NS	NS	**	NS	**	NS	**

^zMean separation within columns by Duncan's NMRT.NS, *, ** Nonsignificant at P $\leq$ 0.05 or 0.01, respectively.

significant statistically, were small and of no practical significance. All treatments supplied adequate N.

The mean leaf concentrations for other nutrients over the 10-year period were not different ($P = 0.05$) for Ca and Zn. Leaf P, Mg, Mn, and Cu were slightly higher for some irrigated trees than for those not irrigated, but the differences were too small for practical significance (Table 4). Leaf Fe was highest for nonirrigated trees. No visual nutrient deficiency symptoms were obvious in the orchard. Except for the possible low K levels in some years (data not shown), leaf nutrient levels were considered adequate for all treatments.

Soil pH for the randomly selected soil samples from outside the wetted zone reflected the acid-forming effect of broadcast N. Soil pH, K, Ca, and

Mg was usually greatest in the plots receiving the low-N-all-fertigated treatment, because no N was applied in the areas sampled (Table 5). Apparently, the H ions formed during the vitrification process of the ammonium nitrate lowered the pH and replaced the basic cations on the exchange complex, thus releasing them to the soil solution for leaching. Soil pH was greater in 4 years when half the N was applied through a drip system than when all was broadcast under nonirrigated trees (data not shown). Soil P was affected very little by the treatments.

A lowering of pH around the emitters when N was fertigated was not observed in this study (Table 6) or that of Aitkin (1986), in contrast to the report of Edwards et al. (1986) for peaches. The calcium hydroxide applied around emitters in 1981 (treat-

ments 3 and 4) might have helped to prevent excessive pH reduction in the wetted zone. Irrigation without the calcium hydroxide (treatment 2) increased the pH in the wetted zone compared with the nonirrigated control. This suggests that basic minerals in the irrigation water might be preventing a lower pH in the wetted zone. An analysis of the irrigation water in 1993 revealed $0.95 \mu\text{g}\cdot\text{g}^{-1}$ Ca, $1.81 \mu\text{g}\cdot\text{g}^{-1}$ Mg, and $4.11 \mu\text{g}\cdot\text{g}^{-1}$ Na, which would have reduced much of the acidity created by the N. Irrigation caused an unexplained loss of soil test P in the wetted zone. Irrigation + fertigation also increased soil test Ca and Mg concentrations in the wetted zone compared with soil tests from the broadcast nonirrigated plots. Much of this increase could have come from the calcium hydroxide and the irrigation

Table 6. Soil analysis in the wetted zone around emitters compared with nonirrigated soil.

Broadcast (lb/acre)	Fertigated (lb/acre)	Drip irrigated	PH	Soil analysis (emitter; 7-year mean)			
				P (lb/acre)	K (lb/acre)	(lb/acre)	(lb/acre)
200	0	No ^r	4.99 a	85 b	126 a	951 a	222 a
200	0	Yes	5.25 b	68 a	134 a	1086 ab	283 b
100	100	Yes	5.28 b	68 a	127 a	1282 bc	270 b
0	100	Yes	5.41 b	63 a	130 a	1340 c	312 b
Interaction							
Fertilizer x year			**	**	**	NS	NS
LSD (0.05), N = 164			0.20	11.1	22.6	201	40.4

^rSoil test for the nonirrigated trees was the general sample.

^{*}Mean separation within column by Duncan's NMRT (P = 0.05).

^{NS,*} Nonsignificant or significant at P ≤ 0.01, respectively.

water. More Ca and Mg were retained in fertigated soil around the emitter compared with nonirrigated soil.

The data from this study indicate that nitrogen can be applied efficiently through the drip irrigation system without detrimental effects on soil and leaf nutrient concentrations. In fact, lowering the soil pH and loss of soil nutrients over the general orchard floor (outside the wetted zone) was reduced when N was fertigated instead of broadcast with no irrigation. Yield and kernel quality were as good under fertigation as when N was broadcast, and the low-N-all-fertigated treatment was adequate. Irrigation with or without fertigation enhanced yields in several years and increased nut size. Leaf N concentrations were near or above the adequate range and suggest that the N application levels can be reduced further. The tests are being continued with the rates of N halved.

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