Nitrogen and Potassium Application Scheduling Effects on Drip-irrigated Tomato Yield and Leaf Tissue Analysis

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Abstract. Tomato (*Lycopersicon esculentum* Mill.) was grown with drip irrigation on an Arredondo fine sand and on an Orangeburg fine sandy loam to evaluate the effect of N and K time of application on petiole sap, leaf-N and -K concentrations, fruit yield, and to determine N and K sufficiency ranges in leaf tissue. On the sandy soil, N-K at 196-112 kg-ha⁻¹ were applied 0%, 40%, or 100% preplant with the remainder applied in 6 or 12 equal or in variable applications in 12 weeks. With the variable application rate, most nutrients were applied between weeks 5 and 10 after transplanting. On the sandy loam soil that tested high in K, only N (196 kg-ha⁻¹) was applied as above. Petiole sap K concentration declined during the season, but was not greatly affected by treatment. Petiole NO₃-N concentrations decreased during the season from 1100 to 200 mg-L⁻¹, and the decrease was greater with preplant N treatments. On the sandy soil, marketable fruit yields were lowest with 100% preplant, intermediate with 100% drip applied (no preplant N), and highest with 40% preplant and 60% drip applied. With 100% drip applied, yields were higher with 12 even applications than with either six even weekly applications or with 12 variable N and K applications. With 40% preplant, timing of application had little effect on yield. On the sandy loam soil in 1993, yields were highest with 100% preplant, intermediate with 40% preplant and 60% drip applied, and lowest with all N drip applied. In 1994 when excessive rains occurred, yields were similar with all preplant and with split N applications. Petiole N concentration was correlated with tomato yield, especially at 10 weeks after transplanting. The best correlation between sap-N and total yields occurred between 4 and 6 weeks at Gainesville and between 4 and 10 weeks at Quincy.

Drip irrigation is an effective way to provide water for tomatoes (Locascio and Myers, 1974). Water use with drip irrigation is considerably lower than with the subsurface and overhead irrigation systems (Clark et al., 1991; Hochmuth, 1994b; Locascio et al., 1989; Persaud et al., 1976). In addition, improved nutrient efficiency with improved yields (Cook and Sanders, 1991; Dangler and Locascio, 1990; Hochmuth, 1992; Hochmuth and Clark 1991; Locascio et al., 1985, 1989) have been demonstrated with drip irrigation. On sandy

soils, nutrients must be applied with the irrigation water (fertigation) to obtain highest yields (Dangler and Locascio, 1990; Locascio and Myers, 1974; Locascio et al., 1989). However, studies on the evaluation of scheduling of drip-applied nutrients are limited (Dangler and Locascio, 1990).

Plant leaf and sap analysis can be important tools for monitoring crop performance in relation to a nutrient management program (Coltman, 1987; Coltman and Riede, 1992; Hochmuth et al., 1991b; Olsen and Lyons, 1994; Prasad and Spiers, 1985; Scaife and Stevens, 1983). Sufficiency ranges for nutrient concentrations of whole leaves have been developed for tomato in Florida (Hochmuth et al., 1991b). Although the use of leaf analyses is considered to be routine, its cost and the relatively long time required to obtain results are problems for growers. Research was begun in the mid-1980s to calibrate fresh petiole sap

quick-test procedures for determining N and K concentrations of Florida tomato plants in an economical and timely fashion. Published guidelines for petiole sap testing for tomato in Florida are based on results with crops grown with subsurface irrigation and all fertilizer applied preplant. Evaluations of petiole sap testing with drip irrigation and fertigation have not been conducted. With the increase in use of fertigation with drip irrigation in Florida tomato production, there is a need to develop sufficiency ranges for leaf and petiole sap testing for fertigated tomato.

Studies reported here were conducted to evaluate the effects of selected N and K fertigation programs on tomato yield and fruit quality on two different soil types, and to determine the effects of fertigation on petiole sap and leaf-N and -K concentrations.

Materials and Methods

Studies were conducted at Quincy, Fla. (Spring 1993 and 1994) and at Gainesville, Fla. (Spring 1994) to compare the effects of time of N and K application on production of drip-irrigated tomato. The Quincy sites were on Orangeburg fine sandy loam soil (fine-loamy, siliceous, thermic, Typic Paleudults) at the North Florida Research and Education Center. The Gainesville study was on an Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudults) located at the Horticultural Research Unit of the Univ. of Florida. The soils tested high in P at both locations and tested high in K at Quincy but medium at Gainesville with a Mehlich-1 extraction. At both sites, total N was applied at 196 kg-ha⁻¹. At Quincy, no K was applied but at Gainesville 112 kg-ha⁻¹ was applied. The sources of N and K nutrients were ammonium nitrate and potassium chloride, respectively.

In 1993 at Quincy, N was applied 0%, 40%, or 100% preplant with the remaining 100% or 60% applied with drip irrigation. Fertigated N was applied at either 8.3% per week for 12 weeks or 16.7% per week for 6 weeks. In 1994 these fertigation schedules were again used for N at Quincy and for both N and K at Gainesville. In addition, a 12-week variable schedule proportional to crop growth was studied. In the variable schedule, fertigated nutrients were applied 2 weeks at 5% each, 2 weeks at 7.5% each, 6 weeks at 10% each, and 2 weeks at 7.5% each (Table 1).

Tomato plants were transplanted in single rows on polyethylene mulched beds fumigated with 98% methyl bromide-2% chloropicrin at 225 kg-ha⁻¹. Beds were 9.2 m long, 1.8 m apart on centers with 1 m across the bed top. Plants were spaced 0.51 m apart at Quincy and 0.46 m apart at Gainesville. Drip irrigation tubing with emitters spaced 0.3 m apart was positioned 0.05 m from the center of the bed. Irrigations were scheduled and tensiometers were programmed to irrigate when the soil water tension reached 10 kPa at 0.15 m depth (Locascio and Smajstrla, 1996). At each irrigation, a water quantity equal to 0.50 time pan evaporation was applied. The water amount was calculated on a field surface area basis but

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Table 1. Treatments used in tomato fertigation studies at Quincy and Gainesville.

Treatment (no.)	Preplant (kg·ha ⁻¹)	N applied		
		(kg·ha ⁻¹)	(kg·week ⁻¹)	Weeks (no.)
1	0	196	16.3	12
2	0 ^a	196	32.7	6
3	0	196	Variable	12 ^b
4	78	118	9.8	12
5	78 ^a	118	19.6	6
6	78	118	Variable	12 ^a
7	196	0	---	
8	0	0	---	

^aNot included in 1993 study.^bGrowth curve fertigation (weeks at kg·week⁻¹), 2 at 14.7, 6 at 19.6, last 2 at 14.7.^cGrowth curve fertigation (weeks at kg·week⁻¹): 2 at 5.9, 2 at 8.9, 6 at 11.8, and last 2 at 8.9.

applied only to the soil under the mulch. Tomatoes were staked, pruned, tied, and pests were controlled with applications of labeled pesticides.

The most-recently matured whole leaves were sampled for N and K analyses at 4, 6, 8, and 10 weeks (after planting) at Gainesville (1994) with an additional sampling at week 12 at Quincy. Leaf samples were analyzed for total Kjeldahl N and K. Petiole sap was analyzed for nitrate-N and for K using specific-ion electrodes. Six whole leaves were sampled per plot (leaf blades and petioles), dried at 70 °C, ground, and 0.5-g samples were digested in sulfuric acid and hydrogen peroxide. The N was determined with rapid flow colorimetry and K by plasma emission spectroscopy at Gainesville. At Quincy, N was determined by micro-Kjeldahl procedures and K by flame emission spectrophotometry. Four leaves were sampled per plot for fresh sap analyses. Petioles and center midribs were excised, chopped, and the sap was extracted with a hydraulic press. Concentrations of NO₃-N and K in the fresh sap were measured with hand-held, battery-operated ion-specific meters (Cardy ion meter; Horiba, Japan).

Tomatoes were harvested twice each season at the breaker maturity stage and graded into extra large, large, medium, and cull categories according to U.S. Grade Standards (U.S. Dept. of Agriculture, 1976). Experimental treatments were arranged in randomized complete-block designs with four replications. Data were tested by analysis of variance and

regression analysis. Mean separation was by orthogonal comparisons.

Results and Discussion

Tomato yields were highly responsive to application of N at Quincy and to N and K fertilization at Gainesville (Table 2). Without application of fertilizer, total marketable seasonal yields were only 52%, 24%, and 24% of yields obtained with fertilization at the Quincy 1993, 1994, and Gainesville 1994 sites, respectively.

Preplant fertilizer. At Quincy, the early marketable yields, total yields of extra large fruit, and total marketable yield in 1994 were similar with 0%, 40%, and 100% preplant applied fertilizer. However, the total marketable yield at Quincy in 1993 was significantly higher with 100% preplant compared with no preplant or 40% preplant applied fertilizer (Table 2). At Gainesville, on a coarse-textured soil, application of 40% and 100% preplant fertilizer resulted in higher yields of early extra large and total early marketable fruit than with no preplant fertilizer. Yields of total extra large and total marketable fruit were significantly higher with 40% of the fertilizer applied preplant than with no preplant fertilizer or with 100% preplant fertilization. Total seasonal extra large and marketable fruit at Gainesville were affected by treatment in the following order: 40% > 100% > 0%.

Yield data from Gainesville showed that on sandy soils, yields were improved with

some fertilizer applied preplant. However, with application of 100% N and K preplant, yields were reduced, possibly due to soluble salt burn of plants early in the season (but no symptoms were evident) and later during the season possibly due to accumulated leaching losses of the fertilizer. On finer-textured soils, the proportion of preplant fertilizer was not as critical (Locascio et al., 1989), although in one season, higher yields resulted when all fertilizer was applied preplant. In past studies on coarse-textured soils (Locascio et al., 1989), application of 40% of the fertilizer preplant resulted in higher yields than with all fertilizer applied preplant.

Fertilizer schedule. The injection schedule for application of 60% or 100% of the N (and K) in 6 or 12 equal weekly or in 12 variable weekly amounts had no effect on yields of extra large or total marketable yield in all three studies (data not shown). These data are consistent with results reported by Dangler and Locascio (1990) and Locascio and Smajstrla (1989).

Leaf nutrients. Leaf-N and -K concentrations responded dramatically to N and K fertilization (Figs. 1 and 2). Leaf-N concentrations of less than 28 g·kg⁻¹ at first flower (after week 4) are considered to be deficient (Hochmuth et al., 1991b). Concentrations of N in leaves reached deficiency status in nonfertilized plants by week 6 in two of the experiments and by week 8 in the third study (Fig. 1). Leaf-K concentrations were increased by fertilization at several sampling periods in both seasons at Quincy (Fig. 2 B and C). Leaf-K concentrations of N fertilized plants remained above sufficiency levels all season in both Quincy experiments. Even though plants were fertilized with K at Gainesville, leaf-K decreased to deficiency concentrations by week 10 (Fig. 2A). Possibly not enough K was applied (112 kg·ha⁻¹) at Gainesville. In recent studies, responses to higher K rates than indicated by soil testing have been obtained at some sites (Hochmuth et al., 1991a; Locascio et al., 1994). This K deficiency may indicate that the K fertilization rate based on soil test results was set too low to satisfy the crop K requirement, or K may be too mobile for calibrated soil testing to work as a predictive

Table 2. Effects of time of fertilizer application and fertigation schedule on tomato yield in three seasons at two sites in Florida.

Treatment	Yield (t·ha ⁻¹)											
	Quincy, Spring 1993				Quincy, Spring 1994				Gainesville, Spring 1994			
	Harvest 1		Total season		Harvest 1		Total season		Harvest 1		Total season	
	Extra large	Total market	Extra large	Total market	Extra large	Total market	Extra large	Total market	Extra large	Total market	Extra large	Total market
Fertilization ^a												
With	14.3	16.5	38.4	48.2	16.5	20.2	34.2	52.9	7.8	12.9	16.8	38.9
Without	9.3	11.8	17.9	24.9	6.2	7.8	7.0	12.9	1.7	4.8	2.2	9.2
Significance ^b	*	*	**	**	**	**	**	**	**	**	**	**
Preplant fertilizer (%) ^a												
0	13.2	15.1	35.3	43.4	16.2	19.6	34.2	52.1	5.6	10.1	14.3	35.0
40	14.6	16.8	38.9	48.7	17.4	21.6	35.0	54.9	9.5	15.1	20.7	43.1
100	15.7	18.5	43.7	56.8	15.1	17.6	31.9	50.7	8.7	14.8	15.1	37.2
Significance ^c				40 vs. 100**					0 vs. 40**	0 vs. 40**	0 vs. 40**	0 vs. 40**
											40 vs. 100**	40 vs. 100**

^aFertilization comparison involves treatments 1 through 7 vs. 8 (see Table 1).^bContrasts significant at $P \leq 0.05$ (*) or 0.01 (**). All other contrasts nonsignificant.^cPreplant fertilizer at 0%, 40%, or 100% of total N and/or K applied preplant incorporated in the bed. Remainder of fertilizer injected through drip system.

tool. Leaf-K concentrations were higher at Gainesville for plants that received no N fertilizer (K only) than for plants that received N and K fertilizer. Leaf analyses data indicated that, in these experiments, N nutrition was the major limiting factor related to treatments at the three sites.

Amount of preplant fertilizer had little effect on leaf-N or -K concentrations in either Quincy experiments (Figs. 1 B and C, 2 B and C). Although there were slight differences in leaf-N and -K concentrations among treatments, leaf-N and -K concentrations were above sufficiency levels. Leaf-N concentration was significantly affected by time of fertilizer application only at the week 8 tissue sampling at Quincy 1993. Leaf-N concentration was higher in plants with 100% N applied preplant than with 0% or 40% preplant fertilizer. This higher N concentration may have been responsible for the increase in total yield with the former treatment.

At Gainesville, N concentrations remained above sufficiency levels for the season with the 0% and 40% preplant treatments (Fig. 1A). Leaf-N fell to deficiency levels after week 8 when all N was applied preplant. Leaf-K was rarely affected by preplant N treatment at Quincy and all values were in the sufficiency range (Fig. 2 B and C). At Gainesville, leaf-K concentrations declined to deficiency concentrations with all treatments after week 8 (Fig. 2A). Leaf-K concentrations at Gainesville were generally at deficient concentrations with all treatments so that N nutrition was probably still the controlling factor for yield response to treatment.

Fertilizer schedule. Injection schedule or timing of N (and K) application in 6 or 12 drip applications had little effect on leaf-N or -K concentrations in any experiment (data not shown). Leaf-N remained above sufficiency levels with all times of application for the entire season in all experiments except for week 14 at Quincy 1993. Leaf-K fell to deficiency levels with all treatments after week 12 at Quincy 1993, and after week 8 at Gainesville.

Leaf tissue analysis data indicated that the most likely controlling factor for yields in these experiments was N nutrition. Treatments that resulted in higher leaf-N at the beginning of the season and that maintained adequate N through week 8 resulted in higher yields than those treatments that did not. Differences in K nutrition had little relation to yield responses in these experiments, although at Gainesville, leaf-K was extremely low by week 10. This low K concentration could have been a factor in the reduced yields at the Gainesville location compared to yields at Quincy.

Petiole sap nutrients. Nitrate-N concentrations of fresh petiole sap responded dramatically to fertilization (Fig. 3); petiole K concentrations did not respond as greatly to N fertilization (Fig. 4). Without N fertilization, petiole sap $\text{NO}_3\text{-N}$ fell to extremely low concentrations by week 6 in all experiments. Concentrations of petiole sap $\text{NO}_3\text{-N}$ below $1000 \text{ mg}\cdot\text{L}^{-1}$ by week 6 (first open flowers) were considered deficient (Hochmuth, 1994b). Petiole sap K remained above sufficiency levels all season

Fig. 1. Leaf-N concentrations as influenced by percentage of N applied preplant (0%, 40%, or 100%) and by no N fertilization at (A) Gainesville 1994, (B) Quincy 1994, and (C) Quincy 1993. Mean concentrations were significantly different ($P \leq 0.05$) with fertilizer than with no N fertilization except at location C at week 4 and week 12. At location A, differences were significant with 0% vs. 40% preplant and with 40% vs. 100% preplant at each sample date. At location C on week 8, effects of 100% vs. 40% preplant were significant.

Fig. 2. Leaf-K concentrations as influenced by percentage of N applied preplant (0%, 40%, or 100%) and by no N fertilization at (A) Gainesville 1994, (B) Quincy 1994, and (C) Quincy 1993. Mean concentrations were significantly different ($P \leq 0.05$) with fertilizer than with no N fertilization except at location A weeks 4 and 6, location B on weeks 4 and 12, and location C weeks 10 and 12. Differences between 0% vs. 40% preplant were significant at location B on week 6 and location C on week 4. At location A on week 8, the difference with 40% vs. 100% preplant was significant.

Fig. 3. Leaf petiole sap $\text{NO}_3\text{-N}$ concentrations as influenced by percentage of N applied preplant, (0%, 40%, or 100%) and by no N fertilization at (A) Gainesville 1994, (B) Quincy 1994, and (C) Quincy 1993. Mean $\text{NO}_3\text{-N}$ concentrations were significantly different ($P \leq 0.05$) with fertilizer than with no N fertilizer except at location B at 10 and 12 weeks and location C at 12 weeks. At location A, differences between 0% and 40% preplant were significant at week 8. At location C on weeks 8 and 12, differences in values for 0% vs. 40% and for 40% vs. 100% were significant.

Fig. 4. Leaf petiole sap K concentrations as influenced by percentage of N applied preplant (0%, 40%, or 100%) and by no N fertilization at (A) Gainesville 1994, (B) Quincy 1994, and (C) Quincy 1993. Mean concentrations were significantly different ($P \leq 0.05$) with N fertilizer with no fertilizer at location A for weeks 6, 8, and 10 and at locations B and C at week 6. At location A on week 8, concentrations were significantly different with 40% vs. 100% preplant.

at all location, except for plants fertilized with N and K after week 8 at Gainesville (Fig. 4A). Petiole K concentration below $3000 \text{ mg}\cdot\text{L}^{-1}$ after week 8 indicate K deficiency (Hochmuth, 1994a).

At Quincy, 1993, petiole sap $\text{NO}_3\text{-N}$ concentrations decreased during the season with all treatments, but fell to lower concentrations with the no preplant fertilizer treatment than with the 100% preplant treatment and were intermediate with the 40% preplant fertilization (Fig. 3C). These data showed that, when the preplant N amount was below 100%, the plant contained less $\text{NO}_3\text{-N}$ and injection of N did not increase the $\text{NO}_3\text{-N}$ concentrations. Possibly, $\text{NO}_3\text{-N}$ was rapidly reduced in plants receiving N only from small amounts of injected N so that little $\text{NO}_3\text{-N}$ accumulated in these plants, or that fertilizer amounts were never high enough at any one injection to maintain a high $\text{NO}_3\text{-N}$ concentration in the petiole sap. A combination of these reasons may be responsible for the yield responses at Quincy 1993, where yield was reduced with the no preplant treatment because $\text{NO}_3\text{-N}$ concentrations were low early in the season and were not recovered by fertigation. Leaf-N also fell by week 8 to concentrations lower than those of plants with 40% or 100% N preplant (Fig. 1).

Petiole sap $\text{NO}_3\text{-N}$ concentrations at Gainesville decreased with all treatments by week 8, although decreases were greatest with plants with all preplant N and K (Fig. 3). Currently, published sap $\text{NO}_3\text{-N}$ sufficiency ranges (Hochmuth, 1994a) appear to be adequate for the early and late-season values based on a comparison with sap $\text{NO}_3\text{-N}$ profiles of the better performing treatments in these experiments. Values for midseason, weeks 6 through 10, in these experiments with the better treatments were 10% to 15% higher than published values.

Preplant fertilizer amount had little effect on petiole sap K concentrations (Fig. 4). Petiole sap K concentrations remained above sufficiency levels in both years at Quincy. At Gainesville, petiole sap K concentrations fell to deficiency levels (below $3000 \text{ mg}\cdot\text{L}^{-1}$) after week 8 (Fig. 4A).

Timing and scheduling of injected fertilizer had little influence on petiole sap $\text{NO}_3\text{-N}$ (Fig. 3) or on petiole sap K (Fig. 4) concentrations. Although, at certain times in the season, statistically significant differences were observed, e.g., at weeks 6 and 8 at Quincy 1994, and weeks 6 and 10 at Gainesville, concentrations with all three treatments would have been placed in the same sufficiency (or deficiency) category according to published sufficiency ranges (Hochmuth, 1994a).

Nutrient injection schedule had no effect on petiole sap K concentrations (Fig. 4). Petiole sap K remained above sufficiency levels all season except for the last sampling at Quincy 1993 and 1994, and except for the last two samplings at Gainesville.

Correlations of leaf tissue sap N and leaf-N concentration of samples taken at 4 weeks and at 10 and 12 weeks (late) were poorer than correlations of samples taken at 6 and 8 weeks

(Fig. 5). The highest correlations occurred when both samples were taken at the same time (either 6 or 8 weeks). Overall, correlation coefficients were higher with samples taken at Quincy than at Gainesville.

Correlation between week sampled for leaf-N concentration and marketable yields (Table 3) were significant at all locations and on all weeks except at week 4 at 1993 Quincy. The highest correlations occurred with leaf-N samples taken at 6 weeks. Leaf-N sap sample time (Table 3) correlated well with total yield at weeks 6, 8, and 10 at Quincy in 1993, weeks 4, 6, and 8 at Quincy in 1994, and weeks 4 and 6 at Gainesville. Correlation coefficients were lower with samples taken at the end of the season than those taken earlier.

Fertilizer N management with drip-irrigated tomatoes is important for highest yields. Data from these studies indicated that tomatoes responded best when 40% of the N was applied preplant on a fine sandy soil. This result was similar to previous research where N applied with drip irrigation resulted in higher yield than with all N applied preplant (Locascio et al., 1989). Yield response to preplant N was not always higher on the finer-textured soils, a result previously reported (Locascio et al., 1985, 1989). Injection schedule and N application timing had little effect on yield or leaf tissue N concentrations. With 40% of the N applied preplant, the schedule of injected N had little effect on yield. Nitrogen can be applied in as few as six or in 12 weekly injections. Nitrogen can also be applied daily or weekly (Locascio and Smajstrla, 1989).

Leaf-N and petiole sap $\text{NO}_3\text{-N}$ concentrations were both responsive to fertilization in these experiments. Petiole sap $\text{NO}_3\text{-N}$ concentration was a good indicator of leaf-N concentration and a good predictor of yield potential. Petiole sap analysis was easy and quick, and would be a useful tool for in-field measurements on tomato farms. The relationships between sap $\text{NO}_3\text{-N}$ and leaf-N were higher when both samples were taken on the same day than weeks apart. Also, the relationships between leaf-N or sap $\text{NO}_3\text{-N}$ and total yield were more similar early in the season than later in the season. During that early period, coefficients were higher with leaf-N than sap $\text{NO}_3\text{-N}$ and yield.

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Fig. 5. Correlation coefficient of sap N concentration vs. leaf-N concentration by week sampled at (A) Gainesville 1994, (B) Quincy 1994, and (C) Quincy 1993. At locations A and B, $r = 0.35$ and 0.45 significant at $P \leq 0.05$ and 0.01 , respectively. For location C, $r = 0.40$ and 0.51 significant at $P \leq 0.05$ and 0.01 , respectively.

Table 3. Correlation of leaf petiole sap N concentration by week sampled and between leaf-N concentration by week sampled and total fruit yields at Gainesville 1994 and Quincy 1993 and 1994.

Location	Sample time after transplanting (weeks)				
	4	6	8	10	12
<i>Sap N concentration (r)</i>					
Gainesville 1994	0.41*	0.60*	0.07	-0.44*	
Quincy 1994	0.66**	0.83**	0.85**	0.42*	0.17
Quincy 1993	0.35	0.72**	0.70**	0.68**	-0.04
<i>Leaf-N concentration (r)</i>					
Gainesville 1994	0.46**	0.57**	0.47**	0.35**	
Quincy 1994	0.66**	0.78**	0.64**	0.59**	0.53**
Quincy 1993	0.16	0.68**	0.64**	0.53**	0.57**

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

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