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Water Quantity and Time of N and K Application for Trickle-irrigated Tomatoes

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Abstract. **Tomatoes (*Lycopersicon esculentum* Mill.) were grown during two seasons at two locations on fine sands and fine sandy loam soils to study the influence of water quantity, frequency of water application, and timing of N and K application for polyethylene-mulched, trickle-irrigated fresh-market tomatoes. Water quantities were 0.50 and 1.0 times pan evaporation applied one or three times daily. Nitrogen and K were applied 100% preplant or 40% applied preplant and 60% applied with trickle irrigation. Higher tomato leaf tissue N and K concentrations in one of the two seasons and higher fruit yields were obtained with 0.5 than with 1.0 time pan water evaporation on a fine sand at Gainesville, Fla. On a fine sandy loam soil at Quincy, fruit yields were higher in a relatively dry season with the higher water quantity and not influenced by the water quantity applied in the second relatively wet season. The number of daily water applications (one vs. three) at both locations had no effect on N and K uptake or fruit yields. Time of N and K applications had no effect on early yields, but total yields were higher with split than all preplant-applied N and K on the fine sandy soil. Split applications of fertilizer resulted in greater yields of extra-large fruit at mid-season and of extra large and large fruit at late harvest than all preplant-applied fertilizer. On the fine sandy loam soil, time of fertilizer application had no effect on yield.**

Tomatoes produced on coarse-textured soils in Florida generally must be irrigated to minimize moisture stress. Overhead and seepage irrigation are used commonly with the application of 0.38 to 0.50 m or 1.15 to 1.50 m of water applied per season, respectively (8). Trickle irrigation has been used to produce tomatoes with yields similar to those obtained with overhead irrigation, but with one-half as much water (7, 8). In studies on a clay loam soil, non-mulched trickle-irrigated tomatoes obtained 50% to 60% of their total N from the soil and a single preplant band fertilizer application was as efficient in fertilizer recovery as fertilizer applied with the trickle system (11). Growing tomatoes with polyethylene mulch increases the amount of applied N recovered by trickle-irrigated tomatoes and increases yield over non-mulched tomatoes (7, 12). Trickle irrigation can leach soluble nutrients (1, 4); nutrients accumulate below and between emitters (5). Tomatoes (8) and strawberries (10) have responded with increased production with N and K injected into the irrigation water in contrast to all applied preplant. Since nutrient leaching increases with the amount of water applied (9), precise control of the amount of water and frequency of application may eliminate the need to apply nutrients with the irrigation water. Also, numerous small daily water applications may be more efficient in reducing water stress and nutrient leaching than one large daily application.

The purpose of these studies was to evaluate the influence of water quantity and frequency of water and N and K applications on trickle-irrigated fresh-market tomatoes grown on fine sand and on fine sandy loam soils.

Materials and Methods

Studies were conducted during Spring 1984 and 1985 at Quincy and Gainesville, Fla. Treatments were 2 × 2 × 2 factorial combinations of the following: a) water quantity—0.5 and 1.0 time pan evaporation; b) water application frequency—one and three times per day; and c) all N and K applied preplant or 40% applied preplant with 60% applied with trickle irrigation. Studies were conducted on an Orangeburg fine sandy loam (fine-loamy, siliceous, thermic, Typic Paleudults) at Quincy and on an Arrendondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudults) at Gainesville. Preplant soil pH values at 0- to 0.15-m depth ranged from 6.2 to 6.7 and the soils tested medium for P and K. Beds were 1.8 m wide by 11.0 m long and treatments were replicated four times. Fertilizer was applied at 230N–56P–336K ($kg \cdot ha^{-1}$) at Quincy and 224–112P–336K ($kg \cdot ha^{-1}$) at Gainesville plus 45 $kg \cdot ha^{-1}$ of a complete micronutrient mix at each location. Preplant fertilizer was applied broadcast in the bed. For the split N and K treatment, 40% of the N and K and 100% of the P and micronutrients were applied broadcast in the bed and 60% of the N and K were applied with trickle irrigation. Nutrient sources were potassium nitrate, ammonium nitrate, concentrated superphosphate, and micronutrient mix FN 503 (Frit Industries, Ozark, Ala.) at Gainesville and Micromate 2424 (Stoller Chemical Co., Gericho, S.C.) at Quincy. Twinwall (0.25-mm-thick) trickle irrigation hose (James Hardie Irrigation, El Cajon, Calif.) was placed 50 mm to one side of the row center; soil was fumigated with 67% methylbromide–33% chloropicrin mixture, applied at 252 $kg \cdot ha^{-1}$; black polyethylene mulch (1.8 m wide by 0.038 mm thick) was applied to the beds. 'Sunny' tomatoes were transplanted on 26 Mar. 1984 and 20 Mar. 1985 at Quincy and 28 Mar. 1984 and 10 Apr. 1985 at Gainesville. Plants were spaced 0.45 m apart in the bed and staked. Irrigation was applied daily through emitters spaced 0.3 m apart that delivered 2 liters/hr per emitter. Irrigation water amounts were calculated based on the total plot size as 0.50 or 1.0 time evaporation from a U.S. Weather Service Class A pan at each location. Water was applied through the trickle irrigation hoses placed in the bed (the raised bed area was ≈0.5 of the total plot area). The percentages of trickle-applied N and K (60% of total) that were injected into the water each of 12 consecutive weeks were 2%, 4%, 6%, 8%, 12.5%, 12.5%, 12.5%, 12.5%, 7.5%, 7.5%, 7.5%, and 7.5% of the total injected, respectively. Recently matured leaves were sam-

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Table 1. Main effects of season, water quantity, water application frequency, and time of N and K application on marketable tomato fruit yield at two locations.

	Location			
	Quincy		Gainesville	
	Yield (t·ha⁻¹)		Yield (t·ha⁻¹)	
Treatment	Early	Total	Early	Total
Season				
1984	18.5	66.0	5.6	91.8
1985	28.6	57.4	11.1	90.2
Significance	**	**	**	NS
Water quantity (pan evaporation)				
0.5	22.9	61.0[z]	8.0	94.7
1.0	24.2	62.4	8.6	87.5
Significance	NS	NS	NS	**
Water frequency (no./day)				
1	23.9	62.7	9.1[z]	91.4
3	23.2	60.7	7.5	90.7
Significance	NS	NS	*	NS
N and K application time				
Preplant	22.9	60.9	9.0	88.0
Split	24.2	62.5	7.7	94.2
Significance	NS	NS	NS	**

[z]Interactions between season and water quantity and between season and water frequencies were significant (**), data provided in text.
**,*,NSF values significant at the 1% or 5% levels or not significant, respectively.

Table 2. Main effects of N and K application time on early, mid, late, and total yields of marketable tomato fruit at Gainesville (1984 and 1985).

	Yield by fruit-size category (t·ha⁻¹)[z]				
N and K application time	Extra-large	Large	Medium	Small	Total
		Early			
Preplant	6.0	2.1	0.6	0.2	9.0
Split	5.4	1.7	0.4	0.2	7.7
Significance	NS	*	NS	NS	NS
		Mid			
Preplant	31.0	14.7	6.5	0.9	53.0
Split	34.1	12.4	4.9	0.6	52.0
Significance	*	**	**	*	NS
		Late			
Preplant	8.4	8.2	7.6	1.8	26.0
Split	13.7	10.1	8.5	2.2	34.5
Significance	**	*	NS	*	**
		Total			
Preplant	45.4	25.0	14.7	2.9	88.0
Split	53.2	24.2	13.8	3.0	94.2
Significance	**	NS	NS	NS	**

[z]Mean fruit weight (g/fruit) for size categories were as follows: 205, extra large; 150, large; 115, medium; and 85, small.
**,*,NSF values were significant at the 1% or 5% levels or not significant, respectively.

pled for N and K analyses. Total N was determined by micro-Kjeldahl and K by flame emission spectroscopy. At Quincy, fruit harvests were made on 19 and 27 June (early yield) and 7 July (late) 1984, and on 18 and 25 June (early) and 1 July (late) 1985. At Gainesville, harvest dates were 14 and 21 June (early), 28 June and 5 July (mid), and 12 and 19 July (late) 1984; and on 13 June (early), 20 and 27 June (mid), and 3 and 11 July (late) 1985. Soil samples were taken from the bed center and 0.2 m to the side of the bed center away from the trickle line at 0 to 0.1, 0.1 to 0.2, and 0.2 to 0.3 m at Gainesville on 13 June 1984 and 9 July 1985. Soil was dried at 100C and extracted with water (1:1, w/w), and total soluble salts were determined with a conductivity meter. Total soluble salts were calculated at 10% soil water.

Results and Discussion

Season. Early fruit yields were considerably higher at both locations during 1985 than during 1984 due primarily to a colder and wetter period early in the 1984 season that delayed maturity (Table 1). Total yields were similar during the two seasons on the fine sandy soil at Gainesville, but were significantly higher on the fine sandy loam soil at Quincy during 1984 than during 1985. Rainfall patterns differed during the two seasons at the two locations. Rainfall averaged 30 mm·week⁻¹ and was relatively uniform in both seasons at Gainesville. At Quincy, during the 1984 season, rainfall averaged 82 mm·week⁻¹ during the first 3 weeks of the growing season when plant water requirements were low and 33 mm·week⁻¹ during the next 10 weeks. In contrast, in 1985, rainfall averaged only 9 mm·week⁻¹ for the first 6 weeks and 47 mm·week⁻¹ for the next 7 weeks of the season. Pan evaporation varied from 23 mm·week⁻¹ early in the season to 47 mm·week⁻¹ later in the season and averaged 39 mm·week⁻¹ at both locations during both seasons. During the 1985 season at Quincy, rainfall was effectively supplemented with irrigation early in the season, but, later in the season, rainfall exceeded pan evaporation and probably resulted in a slight reduction in yield over that obtained in the 1984 season.

Water quantity. Early fruit yields were not influenced by application of water quantities of 0.5 and 1.0 time pan (Table 1). However, total yields were significantly influenced by water quantity on the fine sandy soils at Gainesville. On the fine sandy loam soil at Quincy, the response to water quantity interacted with year. In 1984, when rainfall was relatively low except early in the season, total marketable yield was significantly greater with 1.0 pan water quantity (69.4 t·ha⁻¹) than with 0.5 pan water (62.5 t·ha⁻¹). During the 1985 season, when rainfall quantities were high late in the season, total yields were similar with application of both water quantities. On the fine sand at Gainesville, mean total marketable yield for the two seasons was 7.2 t·ha⁻¹ greater with application of 0.5 than 1.0 times pan water quantity (Table 1).

On a calcareous desert soil, the yield of trickle-irrigated tomatoes was higher with 40% than 70% of pan evaporation water quantity (6). In previous greenhouse studies on a fine sandy soil, where rainfall did not supplement irrigation water, tomato fruit yields were greater with application of water at 0.5 than 1.0 time pan evaporation and were similar with 0.25 and 0.5 time pan evaporation (9). It would appear from the present field studies and those of others (6, 9) that tomato water requirement is about 0.5 time pan evaporation on the fine sandy soil but between 0.5 and 1.0 time pan on the fine sandy loam soil used in the present study.

Frequency of water applications. Application of water one or three times per day had no effect on total fruit production at the two locations (Table 1). However, early fruit yield at Gainesville was influenced by an interaction with season and water application frequency. Early marketable fruit yields were

Table 3. Main effects of water quantity and N and K application time on tomato leaf N and K concentrations at Gainesville (1984 and 1985).

	Leaf nutrient concn (%)							
	Nitrogen				Potassium			
	1984		1985		1984		1985	
Treatment	17 May	28 June	13 June	9 July	17 May	28 June	13 June	9 July
Water quantity (pan evaporation)								
0.5	4.63	4.14	4.37	4.17	1.95	1.88	1.83	2.25
1.0	4.17	3.39	4.17	3.84	1.73	1.70	1.62	2.07
Significance	**	**	NS	NS	NS	NS	*	NS
N and K application time								
Preplant	4.51	3.79	4.09	3.82	1.88	1.86	1.66	2.08
Split	4.29	3.74	4.44	4.19	1.81	1.73	1.79	2.24
Significance	*	NS	**	*	NS	NS	NS	NS

**,*,NS F values were significant at the 1% and 5% levels or not significant, respectively.

Table 4. Interaction of N and K application timing and water quantity on leaf N and K concentration at the end of the season (9 July 1985) at Gainesville.

	Water quantity (pan evaporation)			
N and K	0.5	1.0	0.5	1.0
application time	N concn (%)		K concn (%)	
Preplant	4.16	3.48*	2.31	1.84*
Split	4.17	4.22NS	2.18	2.30NS
	NS	*	NS	*

*,NS Effects were significant at the 5% level or not significant by F test, respectively.

significantly greater with one than three water applications per day (12.8 and 9.2 t·ha^{-1}, respectively) during the 1984 season, but were not influenced by frequency during the 1985 season (data not shown). Except for this one early yield response to frequency of water application, these data are in contrast to work on a sandy soil where an increase in the number of trickle-irrigations from one to three per day increased total plant dry matter yield and decreased fresh fruit yield (3).

Time of N and K application. The response to time of N and K application was not consistent at the two locations. On the fine sandy loam soil at Quincy, fruit yields were similar with preplant and split N and K applications. On the fine sandy soil at Gainesville, however, total fruit yields were significantly greater with N and K applied with trickle-irrigation than applied preplant. At Gainesville, total fruit yield responses to N and K application time were similar each year (Table 1), but response varied by fruit size category and at different times during the seasons (Table 2). Early marketable yields of all fruit sizes, except large, were not influenced by time of N and K application. The yield of early large fruit was 0.4 t·ha^{-1} greater with preplant than with split-applied N and K. Although the total mid-season marketable yields with the two times of N and K application were not significantly different, yields of extra-large fruit were significantly greater with split N and K application.

Table 5. Main effects of water quantity on soil water concentrations in 1984 and N and K application time on total soluble salts during 1984 and 1985 at the center and side of the bed at three soil depths at the end of the fruiting seasons, Gainesville.

	Soil sample location in bed					
	Center (m)			Side (m)		
Treatment	0–0.1	0.1–0.2	0.2–0.3	0–0.1	0.1–0.2	0.2–0.3
	Soil water, 1984 (% by weight)					
Water quantity (pan evaporation)						
0.5	5.51	6.49	7.43	3.45	4.06	4.78
1.0	8.37	9.13	9.56	5.98	7.75	8.92
Significance	**	**	**	**	**	**
	Soluble salts, 1984 (mg·liter^{-1})					
N and K application time						
Preplant	731	659	615	4423	668	659
Split	953	665	628	1103	634	637
Significance	NS	NS	NS	**	NS	NS
	Soluble salts, 1985 (mg·liter^{-1})					
Preplant	963	566	547	8674	747	613
Split	897	666	706	3041	538	550
Significance	NS	NS	**	**	**	NS

**,NS F values were significant at the 1% level or not significant, respectively.

Mid-season yields of large, medium, and small fruit sizes were significantly greater with all preplant than split-applied N and K (Table 2). The yields of all fruit sizes, except medium-size fruit harvested late in the season, were significantly greater with the split than preplant-applied N and K. Late yields of extra large and large fruit were 5.3 and 1.9 $t \cdot ha^{-1}$ greater, respectively, with split N and K than with preplant-applied N and K. The total marketable yield and total yield of extra large fruit were significantly higher with the split than all preplant N and K treatments. These data on sandy soils are in agreement with earlier findings (7, 8) and studies by Bar-Yosef and Sagiv (2). On the sandy loam soil, the lack of tomato response to trickle-applied nutrients was similar to that reported on a clay loam soil (11).

Leaf N and K concentration. Tomato leaf N concentrations on 17 May and 28 June 1984 and K concentrations on 13 June 1985 were higher with application of 0.5 than 1.0 pan water quantity (Table 3). On 17 May 1984 (7 weeks after planting), leaf N concentrations were higher with preplant than with split N and K application. At that time, 100% and 75% of the N and K had been applied with the two treatments, respectively. On 13 June and 9 July 1985, leaf N concentrations were higher with split than all preplant-applied N and K. At the July 1985 sampling (end of the harvest period), leaf N and K concentrations were influenced by an interaction between water quantity and time of N and K application (Table 4). Leaf tissue N and K concentrations were not affected by time of N and K applications with the 0.5 pan water quantity, and all concentrations were considered adequate for plants at these stages of maturity (8, 13). However, with the application of 1.0 time pan water quantity, leaf N and K concentrations were 21% and 25% higher, respectively, with the split than with all preplant-applied N and K. This difference probably accounts for the higher yields obtained late in the season with split N and K application on the sandy soil.

Soil water and soluble salt concentration. Soil water concentrations at Gainesville measured at the end of the 1984 growing season were higher with 1.0 than 0.5 time pan water quantity in the bed center and on the side of the bed at all sample depths (0 to 0.3 m) (Table 5). Soil water concentrations in the bed averaged 5.3% with 0.5 pan and 8.3% with the 1.0 time pan water quantity and 7.7% in the bed center and 5.8% on the side of the bed. Water quantity and frequency of application had little consistent effect on soil nutrient concentrations. Soluble salt concentrations were similar in the bed center at 0 to 0.2 m with both times of N and K applications. Soluble salt concentrations were higher at the side of the bed in the poorly wetted area at the 0- to 0.1-m soil depth in 1984 and at the 0- to 0.1- and 0.1- to 0.2-m soil depths in 1985 with the preplant fertilization than with split fertilization. This difference in soluble salt concentration indicates that lateral movement from the emitter of trickle-applied N and K was not substantial.

These studies indicate that the response of tomato to water quantity applied by trickle irrigation varies with soil type. On a fine sandy loam soil, yields were not influenced by application of water quantities during one season, but, during a drier season, yields were higher with 1.0 than 0.5 time pan evaporation water quantity. On a fine sandy soil, yields were higher with 0.5 than 1.0 pan water quantity. The highest water quantity on the latter soil probably resulted in lower tissue N and K leaf concentrations and limited yield. The frequency of water application (one or three times a day) had no effect on total marketable yield on the two soils. On the sandy loam soil, where fruit were not sized, total yields were not affected by time of N and K application. On the sandy soil, where total yields were relatively high, late yields of extra large and large fruit were higher with split than with preplant N and K. This would indicate that yield responses to time of N and K application are dependent on the soil type, the water quantity applied, and on the length of the harvest period. A major effect of applying N and K with the trickle system may be to maintain N and K concentrations in the plant relatively late in the season, thereby resulting in increased fruit size and yield later in the season than where all N and K is applied preplant.

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