Yield of Trickle-irrigated Tomatoes as Affected by Time of N and K Application

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Additional index words. drip irrigation, *Lycopersicon esculentum*, microirrigation, plant nutrition

Abstract. Tomatoes (*Lycopersicon esculentum* Mill.) were grown on polyethylene-mulched beds of an Arredondo fine sand during two seasons to evaluate the effects of trickle-applied N and/or K, percentages of trickle-applied N and K (50%, 75%, and 100%), and schedules of N and K application on fruit yield, and leaf and shoot N and K concentrations. The daily irrigation requirement, calculated at 47% of the water evaporated from a U.S. Weather Service Class A pan (E^m), was met by the application of 4.6 mm to 7.2 mm water/day. Fertilizer was injected weekly in a variable (2% to 12.5% of the total amount weekly) or constant (8.3% of the total amount weekly) schedule during the first 12 weeks of each season. Trickle-applied nutrients and trickle-applied percentage of nutrients interacted in their effects on early, midseason, and total marketable fruit yields. When N + K and N were trickle-applied, the mean early total marketable fruit yield decreased linearly from 25.3 t·ha⁻¹ to 16.3 t·ha⁻¹ as the trickle-applied percentage of nutrients increased from 50% to 100%; but when K was trickle-applied (100% preplant-applied N), yields were not affected by the trickle-applied percentage (mean 26.3 t·ha⁻¹). The weekly schedule of N and K injection had no effect on fruit yield or other characteristics. Higher leaf N and K concentrations early in the season were obtained when the respective nutrient was 50% to 100% preplant-applied than when the respective nutrient was 75% to 100% trickle-applied; but late in the season, higher concentrations were obtained when the respective nutrient was trickle-applied. Higher yields, however, were associated with higher early season leaf N concentrations rather than with higher late-season leaf N or K concentrations.

Trickle irrigation is a highly efficient and extremely useful method of water application. With trickle irrigation, however, crop roots are restricted primarily to a small volume of soil near the trickle-emitter outlets, and nutrients may be readily leached from this zone due to the high frequency of water application (Bar-Yosef et al., 1980; Goldberg et al., 1971; Persaud et al., 1976; West et al., 1979). As a result, the potential for nutrient stress in crops grown with trickle irrigation, especially on sandy soils, is high.

Higher yields of tomato (Bar-Yosef and Sagiv, 1982), potato (Singh et al., 1978), and watermelon (Elmstrom et al., 1981; Singh and Singh, 1978) have been reported with trickle-applied N than with preplant-applied N. Yield responses to trickle-applied N have been obtained even when preplant-applied, slow-release N sources were used at 224 kg·ha⁻¹ (Locascio and Martin, 1985; Locascio et al., 1982). Enhanced maturation of tomato has also been observed with trickle-applied N compared to all preplant-applied N (Miller et al., 1981). The accumulation of trickle-applied N by tomato has been described (Bar-Yosef and Sagiv, 1982; Bar-Yosef et al., 1980; Locascio et al., 1982; Stark et al., 1983).

The K demand by tomato increases from the transplant stage through fruit set (Halbrooks and Wilcox, 1980; Widders and Lorenz, 1982). Because of the small root systems of determinant tomato plants, K uptake may be suboptimal (Widders and Lorenz, 1979). The application of fertilizer K through a trickle-irrigation system, therefore, could be a very important technique for obtaining high tomato yields.

Yields of tomato (Locascio et al., 1982; Locascio et al., 1989) and strawberry (Locascio et al., 1977) were greater with ≈60% trickle-applied N + K than with preplant-applied N +

K. Because strawberry yields with 50% trickle-applied N + K exceeded the yield with 100% trickle-applied N + K (Locascio et al., 1977), increasing the proportion of trickle-applied nutrients above 50% may also result in a reduction in the yield of tomatoes. Whether the reported yield responses due to trickle-applied N + K to tomato were due to the availability of N, K, N + K, or the effect of the weekly injection schedule also has not been established. The objective of this work was to examine the effects of trickle-applied N and/or K, percentages of trickle-applied nutrients, and schedules of nutrient application on fruit yield, and shoot production, and elemental concentration of leaf and shoot tissue of tomatoes.

Materials and Methods

Field experiments were conducted in 1984 and 1985 on adjacent areas of an Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudult) [2% organic matter, 28 ppm Melich I extractable K (low), volumetric water content at field capacity 0.11 mm³·mm⁻³] at the IFAS Horticultural Unit near Gainesville, Fla. Fertilizer was applied at 224-112-336-45 kg N-P-K-micronutrient mix/ha from NH₄NO₃, K₂SO₄, concentrated superphosphate, and FN 503 (Frit Industries, Ozark, Ala.). All of the concentrated superphosphate and FN 503 and the portions of the N and K applied preplant were applied broadcast and rototilled into raised beds ≈0.9 m wide and 20 cm high. Treatments were factorial combinations of trickle-applied nutrients (N + K, N, and K), percentages of trickle-applied N and/or K (50%, 75%, and 100%), and applications of N and/or K by a variable (2%, week 1; 4%, week 2; 6%, week 3; 8%, week 4; 12.5%, week 5-8; 7.5%, weeks 9-12) and a constant (8.3% weekly) schedule of percentages of trickle-applied N and/or K. Treatments were replicated four times on one-row plots 10.1 m long with beds spaced 1.83 m apart.

Beds were fumigated with 66% methylbromide-33% chloropicrin at 252 kg·ha⁻¹ in the bed. Biwall (orifice diameter,

Received for publication 14 June 1989. Florida Agricultural Experiment Station Journal Series no. 10021. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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Abbreviations: E^m , water evaporated from a U.S. Weather Service Class A pan.

Table 1. Evaporation (E^{pan}), irrigation, and rainfall totals during crop production.

Month	Water (mm)							
	1984				1985			
	Days	E^{pan}	Irrigation	Rainfall	Days	E^{pan}	Irrigation	Rainfall
March	29-31	7	10	0	---	---	---	---
April	1-30	128	52	98	10-30	113	48	140
May	1-31	182	95	200	1-30	203	94	90
June	1-30	183	95	49	1-30	172	71	153
July	1-12	72	38	50	1-9	54	25	5

0.025 cm; emitter spacing, 30 cm) trickle irrigation tubing (James Hardie Irrigation, El Cajon, Calif.) was placed on the soil surface at the bed center and then covered with black polyethylene mulch (thickness 0.038 cm). 'Sunny' tomatoes were transplanted ≈ 5 cm from the bed center on 29 Mar. 1984 and 10 Apr. 1985. Plants were spaced 0.45 m within rows and staked (12,143 plants/ha). The volume of irrigation water applied daily was calculated weekly at 47% of the mean daily volume of E^{pan} for the previous 10 days. Water (4.6 to 7.2 mm·day⁻¹) was applied to the bed area (0.5 E^{pan} in the total plot area, 1.0 E^{pan} in the bed area) (Table 1).

The fungicide chlorothalonil (tetrachloroisoph thalonitrile) was applied at 2.2 kg·ha⁻¹ twice weekly. Methomyl [S-methyl-N-((methylcarbamoyl)oxy)-thioacetimide (2.8 liter·ha⁻¹)] and *Bacillus thuringiensis* var. kurstaki (1.1 kg·ha⁻¹) were applied weekly to control insects.

Recently matured tomato petioles were sampled at biweekly intervals beginning at 5 and 7 weeks after transplanting in 1984 and 1985, respectively. Above-ground portions of two plants per plot were taken following the last harvest. Tissue was dried in a forced-air drier at 70C and ground to particles with a diameter of <0.6 mm. Total N was determined by the Micro-Kjeldhal method using 200-mg samples (Bradstreet, 1965; Galaher et al., 1975). To determine P, K, Ca, and Mg concentrations; 1.0-g samples were ashed in a muffle furnace at 550C for 8 hr. The ash was brought to a volume of 50 ml with 1 N HCl and filtered. Phosphorus concentrations were determined with a Technicon Auto Analyzer. Potassium, Ca, and Mg concentrations were determined by atomic absorption spectroscopy.

Fruit were harvested at the breaker stage and graded according to the following mean weight categories: large, 205 g; medium, 150 g; and small, 115 g. In 1984, there were two early, one mid-, and two late-season fruit harvests at weekly intervals beginning 1.2 weeks after transplanting. In 1985, there were four (two early, one mid-, and one late-season) harvests beginning 10 weeks after transplanting.

Results and Discussion

The early yield of marketable fruit was higher in 1984 than in 1985, but the total yield was higher in 1985 than 1984 (Table 2). Year and trickle-applied nutrients, however, interacted in their effects on the early yield of large, medium, and total marketable fruit (Table 2). In 1984, the early yields of fruit in all weight categories except small fruit were greater with trickle-applied K (preplant-applied N) than with trickle-applied N + K or N (Table 3). In 1985, however, early yields were similar with all trickle-applied nutrients. During both years, trickle-applied nutrients and the percentage of nutrients trickle-applied interacted in their effects on early yields of medium and total marketable fruit, and midseason total large fruit yields (Table 4). Yields of fruit in most size categories decreased linearly as

Table 2. Main effect of year, trickle-applied nutrient(s), and percentage of nutrient(s) trickle-applied on the early and total yields of tomato fruit.

Trickle-applied treatment	Fruit yield (t·ha ⁻¹)			Total marketable
	Size ^a			
	Large	Medium	Small	
<i>Early</i>				
Year (Yr)				
1984	17.6	8.6	2.1	27.1
1985	11.4	5.3	2.3	19.0
Significance	*	***	NS	*
Nutrient(s) (NUT)				
N + K	12.6 b ^y	6.1 b	2.1	20.8 b
N	13.6 ab	6.2 b	1.9	21.7 b
K	15.6	8.5 a	2.6	26.7 a
Yr × NUT	*	**	NS	***
Percentage (%)				
50	15.8	7.8	2.4	26.1
75	14.4	6.9	2.2	23.5
100	11.6	6.1	1.9	19.6
Significance	L***	NS	NS	L***
NUT × %	NS	*	NS	*
<i>Total</i>				
Yr				
1984	35.1	20.3	10.0	65.3
1985	26.1	21.0	29.7	76.8
Significance	*	NS	***	**
NUT				
N + K	29.7	20.7	19.0	69.3
N	31.1	19.7	22.1	73.0
K	31.1	21.3	18.5	70.8
Significance	NS	NS	NS	NS
%				
50	32.1	21.5	18.8	72.4
75	31.9	20.8	19.6	72.3
100	27.8	19.4	21.2	68.5
Significance	L*	L*	NS	NS
Yr × %	*	NS	NS	*
NUT × %	*	NS	NS	NS

^aMean fruit weights were large, 205 g; medium, 150 g; and small, 115 g.

^yMean separation within columns by Duncan's multiple range test, $P = 0.05$. Absence of letters indicates no significance.

NS, *, **, *** Main effects and interactions were nonsignificant or significant at $P = 0.05$, 0.01, or 0.001, respectively. Significant responses to percentage of nutrients trickle-applied were linear (L).

the percentage of trickle-applied N + K and N increased from 50% to 100%, but yields were similar with 50% to 100% trickle-applied K. Early total marketable fruit yields with 50% trickle-applied N + K or N (50% preplant-applied N, mean yield 25.5 t·ha⁻¹) were similar to the yields obtained with 50% to 100% trickle-applied K (100% preplant-applied N, mean yield 26.6

Table 3. Interaction of year and trickle-applied nutrient on the early yields of medium, large, and total marketable tomato fruit.

Year	Early fruit yield (t·ha ⁻¹) ^z		
	Nutrient(s) trickle-applied ·		
	N + K	N	K
<i>Medium</i>			
1984	7.1 b	7.4 b	11.3 a
1985	5.1	5.1	5.7
<i>Large</i>			
1984	14.1 b	15.6 b	19.6 a
1985	11.0	11.6	11.6
<i>Total marketable</i>			
1984	23.0 b	24.5 b	33.8 a
1985	18.5	18.9	19.6

^zMean separation within years by Duncan's multiple range test at $P = 0.05$. Differences were not significant in 1985.

Table 4. Interaction of trickle-applied nutrient(s) and percentage of nutrient(s) trickle-applied on the early, midseason, and total yields of tomato fruit (mean of 2 years).

Trickle-applied nutrient(s)	Yield (t·ha ⁻¹)			Significance ^z
	Trickle-applied (%)			
	50	75	100	
Early medium fruit				
N + K	7.8	5.9	4.6	L***
N	7.3	6.5	4.9	L**
K	8.3	8.2	8.9	NS
Early total marketable fruit				
N + K	26.4	20.4	15.5	L***
N	24.3	23.6	17.2	L**
K	27.4	26.2	26.2	NS
Midseason large fruit				
N + K	10.1	12.5	8.6	Q**
N	14.0	12.5	9.7	L***
K	9.8	10.8	10.9	NS
-Total large fruit				
N + K	31.9	31.7	25.4	L*
N	34.7	33.7	24.9	L**
K	29.8	30.3	33.2	NS

^zEffects were linear (L) or quadratic (Q) at $P = 0.05$ (*), 0.01 (**), 0.001 (***), or nonsignificant (NS).

t·ha⁻¹). These yields were ≈60% greater than marketable fruit yields obtained with 100% trickle-applied N + K or N (mean yield 16.4 t·ha⁻¹). The yield of midseason large fruit increased from 10.1 to 12.5 t·ha⁻¹, with an increase in the percentage of trickle-applied N + K from 50% to 75%, but decreased to 8.6 t·ha⁻¹ with 100% trickle-applied N + K. The yield of midseason large fruit decreased linearly from 14.0 to 9.7 t·ha⁻¹ with an increase in the percentage of trickle-applied N from 50% to 100%, but the percentage of trickle-applied K had no significant effect on the yield of large fruit (mean yield 10.5 t·ha⁻¹).

The total yield of large fruit was influenced by an interaction between trickle-applied nutrients and trickle-applied percentage similar to that observed at the earlier harvest. As the percentage of trickle-applied N + K and N increased from 50% to 100%, the mean total yield of large fruit decreased linearly from 33.3 t·ha⁻¹ to 25.2 t·ha⁻¹ (Table 4). A similar response was observed in another study with strawberries, where total yields were less when 100% of the N + K was trickle-applied than when 50% of the N + K was trickle-applied (Locascio et al., 1977). In the study reported here, tomato yields were not significantly affected by the percentage of trickle-applied K (preplant-applied

Table 5. Interaction of year and percentage of nutrient(s) trickle-applied on the total yields of large and marketable tomato fruit.

Year	Total fruit yield (t·ha ⁻¹)			Significance ^z
	Trickle-applied (%)			
	50	75	100	
<i>Large fruit</i>				
1984	38.3	37.2	38.3	Q**
1985	26.0	26.5	26.0	NS
<i>Marketable fruit</i>				
1984	69.3	68.9	57.7	Q**
1985	75.4	75.7	79.9	NS

^zResponses to percentage of nutrients trickle-applied were quadratic at $P = 0.01$ (Q**) or nonsignificant (NS).

Table 6. Main effect of trickle-applied nutrient(s) on tomato leaf and shoot N and K concentrations (mean of 2 years).

Trickle-applied nutrient(s)	Nutrient concn (%) ^z					Shoot ^x
	Leaf sampled (wk after transplanting)					
	5 ^y	7	9	11	13	
<i>N</i>						
N + K	5.75 b ^w	4.77	4.80	4.89 a	4.11 b ^v	2.09 b
N	5.82 b	4.89	5.00	4.92 a	4.30 a	2.22 a
K	6.56 a	4.92	4.88	4.33 b	3.82 c	2.21 a
<i>K</i>						
N + K	2.42 b ^w	2.18 a ^v	2.00 a	1.77 a	1.44 a ^v	2.17 a
N	2.54 a	1.99 b	1.64 c	1.17 c	0.93 b	1.62 b
K	2.40 b	1.98 b	1.79 b	1.57 b	1.50 a	2.10 a

^zMean separation in columns by Duncan's multiple range test at $P = 0.05$. Lack of letters indicates no significance.

^ySample taken at 5 weeks in 1984 only.

^xTaken at 17 and 14 weeks after transplanting in 1984 and 1985, respectively.

^vSignificant interactions between trickle-applied nutrient(s) and percentage of nutrients trickle-applied (data shown in Table 7).

^wSignificant interaction between year and trickle-applied nutrients (data shown in Table 8).

N, mean yield 31.1 t·ha⁻¹). These responses indicate the importance of applying N early in the season to obtain high early and total yields of large fruit. The time of application of K, however, was not critical.

The mean total yield of large fruit obtained in 1984 (35.1 t·ha⁻¹) was significantly greater than the yield obtained in 1985 (26.1 t·ha⁻¹) (Table 2), possibly because of the longer growing season (111 and 92 days) and more extended harvest periods (5 and 4 weeks) in 1984 than in 1985. Year and percentage of trickle-applied nutrients interacted in their effects on the total yields of large and marketable fruit (Table 5). In 1984, the yield of total marketable fruit was ≈69 t·ha⁻¹, with 50% and 75% trickle-applied nutrients, but was reduced to ≈58 t·ha⁻¹ with an increase to 100% trickle-applied nutrients. In 1985, the percentage of trickle-applied nutrients had no significant effect on yield.

The weekly schedule of trickle-applied nutrients had few significant effects on the fruit yield or leaf elemental concentrations (data not shown). Since yields were similar with both schedules, the injection of the same amount of liquid N and K fertilizer each week, i.e., the constant schedule, may be simpler than varying the amount of nutrient injected.

Leaf N concentrations 5 weeks after transplanting were lower with trickle-applied N + K and N (mean 5.79%) than with trickle-applied K (100% preplant-applied N, 6.56%) (Table 6).

However, trickle-applied nutrients and percentage of nutrients applied interacted in their effects on leaf N concentration (Table 7). With trickle-applied N + K and N, the mean leaf N concentration decreased linearly from 6.09% to 5.50% as the trickle-applied nutrient percentages increased from 50% to 100%, but with trickle-applied K (preplant-applied N), leaf N concentrations tended to be higher and were similar with all percentages of K application (6.56% mean leaf N concentration). These high early season leaf N concentrations were associated with high early, midseason, and total yields of fruit obtained later in the season (Table 4). Fruit yields, especially in the large fruit size category, tended to be higher with 100% trickle-applied K (100% preplant-applied N) or with 50% trickle-applied N + K or N (50% preplant-applied N) treatments with 75% and 100% trickle-applied N supplied as N + K or N.

At 7 and 9 weeks after transplanting, leaf N concentrations were similar with trickle- and preplant-applied N (Table 6). By 11 and 13 weeks, leaf N concentrations obtained with trickle-applied K (preplant-applied N) were lower than with trickle-applied N + K or N. The higher N concentrations with trickle-applied N indicate the plants used the N applied through the trickle irrigation system. High, fruit yields (Table 4), however, were not associated with high late-season leaf N concentrations. Leaf N concentrations in plants supplied with trickle-applied N decrease as the growing season progresses (Kafkafi and Bar-Yosef, 1980; Locascio et al., 1982; Stark et al., 1983); however, the decreases were less with trickle-applied N than when all N was applied preplant (Locascio et al., 1982).

Leaf K concentrations 5 weeks after transplanting (in 1984) with trickle-applied N + K and K were similar and significantly lower than with trickle-applied N (preplant-applied K) (Table 6). However, trickle-applied nutrients and trickle-applied percentage of nutrients interacted in their effects on leaf K concentration similar to the response observed for leaf N concentrations (Table 7). With trickle-applied N + K and K, mean leaf K concentrations decreased linearly from 2.58% to 2.19% as the trickle-applied percentage increased from 50% to 100%; but the percentage of trickle-applied N (100% preplant-applied K) had no effect on leaf K concentration (mean K concentration 2.54%). At 7 weeks after transplanting, the effects of trickle-applied nutrients on leaf K concentration were not consistent; but from 9 to 13 weeks, the K concentrations were higher with trickle-applied N + K and K than with trickle-applied N (preplant-applied K) (Tables 6 and 8).

The effects of the time of K application on shoot K concen-

Table 7. Interaction of trickle-applied nutrient(s) and percentage of nutrient(s) trickle-applied on tomato leaf N and K elemental concentrations at 5 weeks in 1984.

Trickle-applied nutrient(s)	Nutrient concn (%)			Significance ^z
	Trickle-applied (%)			
	50	75	100	
	N			
N + K	6.08	5.71	5.46	L**
N	6.09	5.84	5.53	L**
K	6.52	6.58	6.58	NS
	<i>K</i>			
N + K	2.52	2.49	2.24	L**
N	2.58	2.58	2.46	NS
K	2.64	2.44	2.14	L***

^zResponses to percentage of nutrient trickle-applied were linear (L) at $P = 0.01$ (**), 0.001 (***), or nonsignificant (NS).

Table 8. Interaction of year and trickle-applied nutrient(s) on tomato leaf N and K concentrations.

Year	Leaf nutrient concn (%)		
	Trickle-applied nutrient(s)		
	N + K	N	K
Nat 13 weeks			
1984	4.46 a'	4.59 a	3.88 b
1985	3.75 b	4.00 a	3.75 b
K at 7 weeks			
1984	2.24 a	1.96 b	1.99 b
1985	2.13	2.06	1.96
<i>K at 13 weeks</i>			
1984	1.90 a	1.09 b	1.75 a
1985	0.99 b	0.78 c	1.15 a

^aMean separation within years by Duncan's multiple range test at $P = 0.05$.

trations at the end of the harvest periods were similar to leaf K concentration effects obtained from 9 through 13 weeks after transplanting; higher K concentrations were obtained with trickle-applied N + K and K than with trickle-applied N (preplant-applied K) (Table 6). The effects of N application time on shoot N concentrations, however, were not consistent with the patterns observed in late-season leaf N accumulations. Shoot N concentrations were lower with trickle-applied N + K than with trickle-applied K (preplant-applied N).

Tomato fruit yields and patterns of elemental accumulation were similar with N and K applied through the trickle irrigation system according to a constant weekly schedule and a variable schedule that reflected the crop growth rate. The most important effect of time of N and K application on fruit yields in this study was the interaction of trickle-applied nutrients and the percentage of trickle-applied nutrients. In both years, higher early, midseason, and total fruit yields, usually in the important larger fruit size categories, were obtained with 50% trickle-applied N supplied as N + K or N than with 75% or 100% trickle-applied N. Significant effects on yield were not obtained by varying the percentage of trickle-applied K from 50% to 100%. Treatments that resulted in high fruit yields also resulted in higher leaf N concentrations early in the season. Late in the season, leaf N and K concentrations were higher with the respective nutrient trickle-applied than with the nutrient preplant-applied. High fruit yields, however, were not associated with these high late-season leaf N or K concentrations. Unlike the response to trickle-applied N, significant effects on fruit yield were not observed by varying the percentage of K applied through the irrigation system. The time of K application, therefore, had less effect on tomato yields than the time of N application.

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