COMMUN. IN SOIL SCI. PLANT ANAL., 16(1), 71-81 (1985)

FRESH-MARKET TOMATO RESPONSE TO N AND K FERTILIZATION AND WATER MANAGEMENT PRACTICES[1]

KEY WORDS: Lycopersicon esculentum, trickle irrigation, soft-fruit syndrome, plant analysis, fertilizer placement, nitrogen potassium

D. L. Karlen, C. R. Camp[2]

Soil Scientist, Agricultural Engineer
USDA-ARS
Coastal Plains Soil & Water Conservation Research Center
Florence, SC 29502

M. L. Robbins[2]

Former Professor of Horticulture
Clemson University, Coastal Experiment Station
Charleston, SC 29407
Resident Director, LSU Research Stn., Chase, LA 71324

ABSTRACT

Field experiments were conducted to evaluate N and K fertilization rates, fertilizer placement, and water management practices for fresh-market tomato (*Lycopersicon esculentum* Mill.) production in the Southeastern Atlantic Coastal Plain. Plant nutrient status, fruit yield, and fruit firmness after 12 to 15 days of storage at 20C were evaluated. Nitrogen rates of 130 or 200 kg/ha significantly increased yield of extra-large and large fruit compared to the 67 kg/ha N rate. There was no significant difference in yield response among K rates of 46, 140, or 280 kg/ha. Marketable fruit yields for banded or broadcast placement of fertilizers beneath the black polyethylene mulch were not significantly different. Trickle irrigation did not cause extensive nutrient leaching or induce a "soft-fruit" storage syndrome. The 'Tempo' cultivar yielded significantly more extra-large fruit with or without irrigation. However, after 12 to 15 days at 20C, internal

 0010-3624/85/1601-0071$3.50/0

Communications in Soil Science and Plant Analysis

Communications in Soil Science and Plant Analysis presents current and important papers, symposia, and reviews in all areas of crop production, devoting particular attention to the mineral content of soils and plants and plant nutrition. This unique publication fully examines soil chemistry, minerology, fertility, soil testing, soil-crop nutrition, plant analysis, mineral metabolism and plant physiology, methods of soil and plant analysis, liming and fertilization of soils, and techniques for correcting deficiencies. International in scope and application, the journal considers plants and soils of all climates, including subtropical and tropical. In addition, its direct reproduction format permits rapid publication of important developments, keeping readers abreast on research at the frontiers of their field.

Whether engaged in basic or applied investigations or in communicating techniques and information directly to growers, **Communications in Soil Science and Plant Analysis** provides an excellent source and forum for agronomists, horticulturalists, floriculturalists, and foresters concerned with increasing crop yields.

firmness of physiologically similar fruit was lower for 'Tempo' than for the 'Flora-Dade' cultivar. These results provide management guidelines for intensive tomato production in the Southeastern Atlantic Coastal Plain.

INTRODUCTION

Fresh market tomato (*Lycopersicon esculentum* Mill.) production is important in the Southeastern Coastal Plain because during June, this region supplies most fresh-market tomatoes for northern population centers[4]. In South Carolina, for example, the 1979 fresh-market tomato crop had a farm value in excess of $13 million, while in 1981 the farm value was in excess of $20 million. Optimizing production practices is therefore important to all growers.

Cultural practices for tomato production have changed significantly in this region since fertilization practices were evaluated[16]. New practices include mulching with full-bed black polyethylene, staking, and utilizing trickle irrigation to prevent water stress[8,9,12,14]. Although several experiments have been conducted in Florida to determine optimum nutrient and water management practices[7,15,17,18], those results may not be directly applicable in South Carolina because of differences in soil type, growing season, or other environmental factors. Objectives of these two experiments were to evalute N and K fertilization rates, placement of fertilizers, cultivar response, and effects of water management on production of mulched tomatoes.

METHODS AND MATERIALS

Field experiments were conducted at Clemson University's Coastal Experiment Station, near Charleston, S.C., on a Yauhannah (fine-loamy, siliceous, thermic, Aquic Hapludult) loamy fine sand during 1979, 1980, and 1981. Three rates of N (67, 134, and 202 kg/ha) and 3 rates of K (46, 140, and 280 kg/ha) were compared in all combinations each year. In 1979, fertilizer treatments were either broadcast or banded beneath the 0.04-mm thick black polyethylene mulch. An open-pollinated tomato cultivar (Flora-Dade) was grown with irrigation. In 1980 and 1981, all fertilizer treatments were broadcast, but two tomato cultivars (open-pollinated Flora-Dade and a hybrid, 'Tempo') were evaluated with and without irrigation.

Experimental sites were rotated with sweet corn (Zea mays L.) in the same field to minimize disease and insect pressures. Plots were prepared by turn-plowing, disking, and subsoiling prior to forming rough beds on 1.8-m centers. Lime was applied according to soil test recommendations[6] to maintain surface soil pH at approximately 6.0 while P was applied uniformly at an annual rate of 77 kg/ha. A micronutrient mix containing B, Mn, and Zn was applied at recommended rates. Fertilizer N and K treatments were applied prior to fumigating with 336 kg/ha of a 67/33% mixture of Bromomethane/Trichloronitromethane (methyl bromide/chloropicrin). The beds were pressed and covered with 150-cm wide, 0.04-mm thick black polyethylene mulch. One twin-wall[3/] trickle irrigation tube with outlets every 30 cm and a discharge rate of 65 ml/min/m was placed at a depth of 5 cm beneath the mulch approximately 15 cm from the center of the bed.

Tomato seedlings were transplanted 46 cm apart on March 20, 26, and 27 in 1979, 1980, and 1981, respectively. Plants were pruned, and staked. They were sprayed as needed with 6,7,8,9,10,10-Hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzo (e)-dioxathiepin-3-oxide (Thiodan) and Bacillus thuringiensis (Dipel) for insect control; copper for bacteria control; and manganese ethylenebisdithiocarbamate (Maneb) for fungal control. Soil water tensions at the 30-, 60-, 90-, 120-, and 150-cm depths were monitored with vacuum-gauged tensiometers placed between the tomato plants. Irrigation water was applied when soil water tensions at 30 cm exceeded 25 kPa (centibars).

Mature-green, breaker, and ripe fruit were harvested 3 or 4 times each season. Internal fruit firmness was measured by placing 6 mature-green fruit in a constant temperature room at 20C for 12 to 15 days. Ripe fruit were then sliced in half, and resistance of the flesh to crushing was determined with a penetrometer which had a 1 cm^2 flat tip.

Nutritional status of tomato plants was monitored by collecting recently-matured leaves and analyzing them for N, P, and K using standard laboratory methods[11]. In 1979 soil samples were collected from beneath the mulch at depths of 0-15, 15-30, 30-45, 45-60, and 60-90 cm and analyzed for nitrate N to estimate leaching losses. All treatments were replicated 4 times and data were analyzed using a randomized complete block design[19] which had 3 levels of N, 3 levels of K, and 2 methods of fertilizer placement in 1979; and 3 levels of N, 3 levels of K, 2 tomato cultivars, and 2 methods of water management in 1980 and 1981.

RESULTS AND DISCUSSION

Experimental sites used for these studies were typical of soils managed for vegetable crop production in the Southeastern Atlantic Coastal Plain. Initial extractable nutrient concentrations (Table 1) indicated that soil test ratings were "very-high" for P, K, and Mg, "high" for Ca, and "adequate" for Mn and Zn. Fertilizer rates were based on those soil-test results and were therefore equivalent to 0.5, 1.0, or 1.5 and 0.5, 1.5, or 3.0 times current recommendations[6] for N and K, respectively.

Plant analyses showed that at early fruit set, tomato leaf-N, -P, and -K concentrations were proportional to fertilization rates (Table 2), but all values were within the ranges previously published[10]. Yield response to N was less consistent than plant nutrient concentrations, but there were significant increases in extra-large and large fruit for which premium prices are often paid (Table 3). Increase K fertilization rate significantly decreased leaf-N concentration in 1979, but not in 1980 or 1981. Marketable fruit yield showed no significant differences among K fertilization rates.

Tomato plants were physiologically similar in age when leaf samples were collected each year (Table 2), but N and K concentrations were much greater in 1979 than in either 1980 or 1981. Differences in residual soil fertility for experimental sites within the field were suspected to have caused this seasonal difference because fertilization rates were identical. A comparison of field cropping histories supports this hypothesis because the 1979 tomato crop followed an autumn green manure crop of pigeon pea (*Cajanus cajan* L.) while the 1980 and 1981 crops followed autumn crops of sorghum (*Sorghum bicolor* L.).

Total marketable fruit yield averaged 62.2, 46.0, and 54.1 Mg/ha in 1979, 1980, and 1981, respectively. Yields were highest in 1979, and although residual soil fertility was probably a factor, other tomato experiments[14] suggested that a favorable seasonal environment also contributed to those high yields.

Initial Soil Fertility Status of a Yauhannah Loamy Fine Sand Used to Evaluate N and K Fertilizer Rates for Fresh-Market Tomato Production

Sample Depth --cm--	Water pH	Mehlich I Extractable P	K	Ca	Mg	Mn	Zn
		----------mg/kg----------					
0-15	6.0	226	145	403	101	4.4	32
15-30	6.3	194	76	390	103	3.0	31
30-45	5.4	38	69	250	104	1.0	6
45-60	5.0	3	51	193	82	0.1	2

TABLE 2.

Fertilizer N and K Rate Effect on Tomato Leaf-Nutrient Concentrations at Early Fruit Set

Nutrient	1979			1980			1981		
kg/ha	N	P	K	N	P	K	N	P	K
	----------%----------								
67N	5.07	0.52	4.59	3.76	0.50	3.87	3.36	0.36	3.33
134N	5.67	0.48	4.48	3.89	0.47	3.58	3.57	0.36	3.28
202N	6.00	0.47	4.41	3.90	0.49	3.58	3.73	0.36	3.41
LSD(0.05)	0.28	0.02	NS	0.11	NS	0.11	0.10	NS	0.11
46K	5.79	0.51	4.22	3.80	0.50	3.53	3.57	0.36	3.22
140K	5.57	0.48	4.44	3.88	0.49	3.68	3.54	0.36	3.37
280K	5.39	0.48	4.82	3.86	0.48	3.83	3.55	0.36	3.43
LSD(0.05)	0.28	0.02	0.19	NS	NS	0.11	NS	NS	0.11

TABLE 3.

Fertilizer N and K Rate Effect on Marketable Fruit Yields of Tomato

Nutrient	1979			1980				1981			
kg/ha	XL	L	M	XL	L	M	S	XL	L	M	S
	----------Mg/ha----------										
67N	27.1	26.8	3.8	15.2	20.9	3.4	0.7	23.0	17.0	2.0	0.2
134N	29.2	25.2	3.8	17.0	24.2	4.0	0.8	26.6	20.0	2.7	0.4
202N	29.1	29.3	3.8	15.8	24.8	4.1	0.8	30.1	21.5	2.3	0.2
LSD(0.05)	NS	2.9	NS	NS	3.1	NS	NS	5.0	4.3	NS	NS
46K	27.1	27.0	4.0	15.6	22.5	3.7	0.8	27.0	19.8	2.3	0.2
140K	27.8	25.3	3.6	15.8	23.5	4.0	0.8	27.8	19.3	2.7	0.4
280K	30.6	28.9	4.0	16.6	24.8	3.8	0.8	25.3	19.7	2.3	0.2
LSD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

XL = extra-large >73 mm; L = large 64-73 mm;
M = medium 59-64 mm; S = small 54-58 mm.

Banded and broadcast placement of the N and K fertilizer beneath the mulch were compared in 1979. Leaf-N concentrations at early fruit set were significantly greater where the fertilizer was banded, but placement caused no significant differences in marketable fruit yield (Table 4). Analyses of soil samples from beneath the mulch were made to determine if fertilizer placement influenced leaching losses. Those data showed that NO_3-N concentrations in the upper 60 cm were generally greater where fertilizer was banded than where it was broadcast, but this did not influence marketable fruit yield (Table 4). Average profile (0-90 cm) NO_3-N concentrations were 84, 33, 16, 9, and 6 mg/kg in samples collected 16, 38, 59, 78, and 99 days after transplanting, respectively. There were no consistent N rate or placement effects, although uncertainty in locating fertilizer bands caused coefficients of variability to range from 92 to 302% for the five sampling dates.

Decomposing pigeon pea residues, in addition to the fertilizer N, apparently contributed to the high initial soil NO_3-N concentration. However, most of that N was apparently taken up by the tomato crop because leaf-N concentrations 38 days after transplanting exceeded 6.5% for all N treatments. Those plant analyses and the low (<9 mg/kg) NO_3-N concentrations below 60 cm indicated leaching losses were minimal. Similar observations were reported for a study on Norfolk (Typic Paleudult) loamy sand[14], but results of both experiments are contrary to those of Persaud et al.[17,18]. They studied fertilizer N and K placement for tomatoes on Grossarenic Paleaquault and Aeric Haploquad soils in Florida. The importance of soil type and water management when comparing similar fertilizer management practices are emphasized by those contrasting results.

In 1980 and 1981 water management influenced soil water tensions[5], marketable fruit yield, and nutrient concentrations in tomato plants (Table 5). Irrigation significantly increased plant P, presumably because diffusion to root surfaces was enhanced. In 1981, irrigation also increased plant N concentrations, but K concentrations were not influenced by water management. The economic value of using supplemental trickle irrigation to maintain soil-water tensions at less than 25 kPa (centibars) is also evident from these data. In both 1980 and 1981, yield increases occurred in extra-large and large fruit categories for which premium prices are often paid.

TABLE 6.

Cultivar effect on tomato leaf nutrient concentrations and marketable fruit yield in 1980 and 1981

Cultivar	Year	N	P	K	XL	L	M	S
		--------%--------			---------Mg/ha----------			
FloraDade	1980	3.85	0.53	3.75	11.3	27.2	4.4	0.7
Tempo	1980	3.85	0.44	3.60	20.7	19.4	3.2	
LSD(0.05)		NS	0.02	0.09	1.8	2.5	0.5	
FloraDade	1981	3.51	0.39	3.36	18.5	21.2	2.9	
Tempo	1981	3.60	0.33	3.32	34.2	18.1	2.0	
LSD(0.05)		0.08	0.02	NS	5.2	NS	NS	NS

XL = extra-large >73 mm; L = large 64-73 mm;
M = medium 59-64 mm; S = small 54-58 mm.

fertilization and irrigation which created the only significant interactions (N*Var; and N*Var*Irr) in these experiments. The other predominant cultivar difference was that 'Tempo' yielded more extra-large fruit than 'Flora-Dade'. This was probably a genetic difference because it occurred both years (Table 6).

Several tomato growers in the Atlantic Coastal Plain have encountered a "soft-fruit" problem which they feel is related to heavy rainfall or water management practices such as trickle irrigation. Karlen et al.[13] were able to induce similar symptoms by flooding tomato plants grown in a greenhouse, but "soft-fruit" storage characteristics were not induced in these field experiments or those reported previously[14]. However, in all field experiments, soil-water content was monitored with tensiometers and excessive water was neither applied nor received through rainfall.

Internal firmness of physiologically similar fruit after 10 to 15 days of storage at 20C showed no N or K fertilizer rate, fertilizer placement, nor water management effects. There were significant differences in firmness of fruit from the two cultivars (Table 7), but no

TABLE 4.

Fertilizer placement effect on tomato leaf nutrient concentrations and marketable fruit yield in 1979.

Fertilizer Placement	N	P	K	XL	L	M
	----------	%	----------	----------	Mg/ha	----------
Broadcast	5.32	0.50	4.52	27.3	27.1	4.1
Banded	5.84	0.48	4.47	24.6	27.1	3.6
LSD(0.05)	0.23	NS	NS	NS	NS	NS

XL = extra-large >73 mm; L = large 64-73 mm;
M = medium 59-64 mm

TABLE 5.

Water management effect on tomato leaf nutrient concentrations and marketable fruit yield in 1980 and 1981

Water Management	Year	N	P	K	XL	L	M	S
		---------	%	---------	----------	Mg/ha		----------
Nonirrigated	1980	3.81	0.46	3.68	13.8	21.6	3.6	0.7
Irrigated	1980	3.88	0.51	3.68	18.2	25.0	4.0	0.8
LSD(0.05)		NS	0.02	NS	1.8	2.5	NS	NS
Nonirrigated	1981	3.37	0.30	3.33	21.0	16.4	2.4	0.2
Irrigated	1981	3.74	0.42	3.35	32.9	23.1	2.5	0.4
LSD(0.05)		0.08	0.02	NS	5.2	4.5	NS	NS

XL = extra-large >73 mm; L = large 64-73 mm;
M = medium 59-64 mm; S = small 54-58 mm.

The most consistent nutrient difference between cultivars was for P which was consistently greater in 'Flora-Dade' plants (Table 6). Total marketable yield averaged 43.6 and 42.8 Mg/ha for 'Flora-Dade' and 44.2 and 54.6 Mg/ha for 'Tempo' in 1980 and 1981, respectively. Those differences were significant only in 1981 when southern blight caused by *sclerotium rolfsii* significantly reduced the 'Flora-Dade' yield. Severity of that disease was partially reduced by higher N

TABLE 7.

Cultivar effects on firmness of tomato fruit harvested mature green and ripened 12 to 15 days at 21C in 1980 and 1981.

Cultivar	1980 Harvests				1981 Harvests	
	1	2	3	4	1	2
	kg/cm^2					
FloraDade	1.90	2.78	3.22	2.48	1.93	3.37
Tempo	1.34	1.77	1.98	1.72	1.59	2.41
LSD(.05)	.19	.17	.19	.17	.09	.13

symptoms of the "soft- fruit" problem. Differences measured in these experiments were presumably caused by genetic variation rather than any response to fertilization or water management practices.

CONCLUSIONS

For tomato production on Yauhannah loamy fine sand or similar soil types in the Southeastern Atlantic Coastal Plain, our results suggest that N rates should be 130-200 kg/ha and that K rates can be determined by current soil testing methods. Banding or broadcasting fertilizer beneath the black polyethylene mulch were equally effective. Trickle irrigation did not induce a "soft-fruit" condition. Nutrient leaching losses appeared to be minimal, primarily because water applications were closely monitored with tensiometers. Applying supplemental water increased plant P concentrations, and consistently increased extra-large and large fruit yield. Fruit size, leaf P concentration, and fruit firmness were the primary cultivar differences in these experiments.

ACKNOWLEDGEMENT

This research was funded in part by the Southeastern Small Research Center under Cooperative Agreement No. 58-7B30-9-68.

REFERENCES

1. Contribution of the Coastal Plains Soil and Water Conservation Research Center, USDA-ARS, P. O. Box 3039, Florence, S.C. 29502,

and the Coastal Experiment Station, Charleston, S.C. 29407, in cooperation with the South Carolina Experimentation Station, Clemson, S.C.

2. Soil Scientist, Agricultural Engineer, USDA-ARS, Florence, and Former Professor of Horticulture, Clemson University.

3. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

4. Babb, J. H., J. Epperson, and G. J. Wells. 1981. The competitive position of South Carolina's fresh market tomato industry. Bull. No. 644. S. C. Agric. Expt. Stn., Clemson Univ., Clemson, S.C.

5. Camp, C. R., M. L. Robbins, and D. L. Karlen. 1981. Trickle irrigation for tomatoes in the lower Coastal Plain. Paper No. 82-2518. Presented at the 1982 Winter Meeting, Am. Soc. of Agric. Eng., Chicago, IL.

6. Clemson University Coop. Ext. Ser. 1982. Lime and fertilizer recommendations: Based on soil-test results. Cir. 476. Clemson Univ., Clemson, S.C.

7. Csizinszky, A. A., and D. J. Schuster. 1982. Yield response of staked, fresh-market tomatoes to reduced use of fertilizers and insecticides. J. Amer. Soc. Hort. Sci. 107(4):648-652.

8. Doss, B. D., J. T. Turner, and C. E. Evans. 1980. Irrigation methods and in-row chiseling for tomato production. J. Amer. Soc. Hort. Sci. 105:611-614.

Geraldson, C. M. 1975. Evaluation of tomato production efficiency with relevance to contributing componenents. Proc. Fla. State Hort. Sci. 88:152-155.

10. Geraldson, C. M., G. R. Klacan, and D. A. Lorenz. 1973. Plant analysis as an aid in fertilizing vegetable crops. p. 265-279. In: L. M. Walsh and J. B. Beaton (eds.). Soil testing and plant analysis. Soil Sci. Soc. Amer., Madison, Wi.

Issac, R. A., and W. C. Johnson. 1977. Methodology for the analysis of soil, plant, feed, water and fertilizer samples. Univ. Ga. Soil and Plant Anal. Lab., Athens, Ga.

12. Jones, T. L., U. S. Jones, and D. O. Ezell. 1977. Effect of nitrogen and plastic mulch on properties of Troup loamy sand and on yield of 'Walter' tomatoes. J. Amer. Soc. Hort. Sci. 102: 273-275.

13. Karlen, D. L., R. E. Sojka, and M. L. Robbins. 1983. Influence of excess soil-water and N rates on leaf diffusive resistance and storage quality of tomato fruit. Soil Sci. Plant Anal., 14:699-708.

14. Karlen, D. L., and M. L. Robbins. 1983. Management practices for fresh-market tomato production in the Southeastern Coastal Plain. HortScience. 18(5):732-734.

15. Locascio, S. J., J. M. Myers, and J. G. Fiskell. 1982. Nitrogen application timing and source for drip irrigated tomatoes. p. 323-328. In: A. Scaife (ed.). Proc. Ninth Inter. Plant Nutrition Colloquium, Warwick Univ., Warwick, England.

16. Ogle, W. L., K. B. Mack, and W. P. Cook. 1964. Tomato fertilization in Coastal South Carolina. Bull. No. 512. S.C. Agric. Expt. Stn., Clemson College, Clemson, S.C.

17. Persaud, N., S. J. Locascio, and C. M. Geraldson. 1976. Effect of rate and placement of nitrogen and potassium on yield of mulched tomato using different irrigation methods. Proc. Fla. State Hort. Soc. 89:135-138.

18. Persaud, N., S. J. Locascio, and C. M. Geraldson. 1977. Influence of fertilizer rate and placement and irrigation method on plant nutrient status, soil soluble salt and root distribution of mulched tomatoes. Soil and Crop Sci. Soc. of Fla. 35:121-125.

19. Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics: A biometrical approach. Second Ed., McGraw-Hill, Inc., New York, N.Y.