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Sulfur Source, Rate, and Methods of Application for Polyethylene-mulched Tomato[1]

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ABSTRACT

Tomato (Lycopersicon esculentum L.) was grown with polyethylene mulch and drip irrigation on a Millhopper fine sandy soil testing very high in P and low in organic matter during two seasons to evaluate the effect of S source, rate, and application methods on plant growth and yield of fruit. Sulfur rate of 34 and 68 kg S·ha^{-1} were applied with preplant (broadcast in the bed), drip (10 weekly drip application), and by split applications (50% preplant and 50% drip). In split applications, S sources evaluated were ammonium sulfate and ammonium thiosulfate. Plant height was increased with S application from 0 to 68 kg S·ha^{-1} in both studies. However, response on plant dry weight only occurred in spring 1999. Total marketable yield was 17.9 tons·ha^{-1} with 0 kg S·ha^{-1} and was increased linearly to 48.1 tons·ha^{-1} with application of 68 kg S·ha^{-1} in Spring 1999, but no response to S was obtained in the Spring 1998 study. Measured variables were not affected by S source and methods of application. Increasing S application from 0 to 68 kg S·ha^{-1} reduced leaf and plant tissue P concentration 14 and 12% at mid season, 26 and 25% at late season sampling times, respectively. S application of 68 kg S·ha^{-1} reduced soil pH approximately 0.3 unit at the end of the season in both studies.

Key words: drip irrigation, sulfur, fertigation, Lycopersicon esculentum

INTRODUCTION

The sandy soil of northern and central Florida is low in available sulfur. Extractable SO_4-S was less than 6 mg.kg^{-1} and considers very low throughout the profile of Florida Spodosol (Mitchell and Blue, 1981). Lack of S in many fertilizer material used on crop under intensive production system may cause plant nutrient imbalance that reduce yield. Early researchers demonstrated that crop such as white clover (Monteiro and Blue, 1990; Blue and Malik, 1986), sorghum-sudangrass (Mitchell and Blue, 1981) and corn (Blue *et al*., 1981) growing in Florida sandy soil would respond to S application. Response of tomato growth to S application also reported in the greenhouse study by Susila and Locascio (1999).

Fresh market tomato is the most valuable vegetable grown in Florida. During 1998-1999, the crop was grown on 17,577 ha with value of $461 millions or share 29.2% of the total vegetable production value in Florida (Witzig and Pugh, 2000). Tomato is vegetable most widely grown with drip irrigation. Total fruit yield, marketable fruit, and average fruit weight of tomato were higher with drip irrigation than with sub irrigation (Scholberg and Locascio, 1999) Extensive studies have been conducted with drip irrigation to determine the fertilizer requirement of polyethylene-mulched tomato. Yield of tomato were greater with ~ 60 % trickle applied N+K than with preplant applied N+K (Locascio *et al*., 1989). Locascio *et al*. (1997) also showed that on a sandy soil, tomato yield were lowest with 100% N+K applied preplant, intermediate with 100% applied by fertigation, and highest with 40% applied preplant with 60% applied by fertigation.

In coarse-textured, sandy soil, very little sulfate adsorption take place. Mineralized sulfate or sulfate applied in fertilizer may be readily lost by leaching under high rainfall condition which exist during most of the growing season in Florida. Although intensive studies have been conducted on N, K nutrition, however, less attention has been paid to S nutrition in polyethylene-mulched tomato with drip irrigation. Studies reported here were conducted to evaluate the effect of S-source, rate, and methods of application on growth, yield and nutrient concentration of polyethylene-mulched tomato.

MATERIALS AND METHODS

Research was carried out at the Horticultural Research Unit of the University of Florida in Gainesville, FL. during Spring 1998 and Spring 1999.

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Pre fertilizer soil samples were taken with a soil probe from the top 15 cm of an Arredondo fine sand (loamy, siliceous, Hyperthermic, Grossarenic Paleudults). Soil was dried, sieved, and analyzed for P (very high), K (very low) in Spring 1998, and P (very high), K (medium) in Spring 1999 with Melich-I procedures (Hanlon *et al.*, 1994). Low organic matters content were determined in both seasons. Fertilizer was applied at 197-0-209-34 (Spring 1998), and 197-0-93-34 (Spring 1999) kg N-P-K-micronutrient mix.$\cdot$ha^{-1} from ammonium nitrate, potassium chloride, and FN 503 (Frit Industries, Ozark, Ala.). All the micronutrient and 40% of N and K applied preplant, and 60% of N and K were fertigated.

Treatments were combination of S rate (34 and 68 kg S$\cdot$ha^{-1}), method of applications (preplant, drip, and split), and source (ammonium sulfate and ammonium thiosulfate). Preplant applications were applied of fertilizer broadcast and rototilled into raised bed approximately 0.9 m wide and 20 cm high. Drip applications were applied 10 times weekly, and split applications were 50% preplant and 50% drip. In split applications S source were evaluated. Eight treatment combinations and check (0 S) were arranged in randomized complete block design with five replications. Treatment applications are presented in Table 1.

Beds were fumigated with methyl bromide (MB 92-2) at 448 kg on 4 Mar.1998 and 1999. Biwall drip irrigation tubing (orifice diameter, 0.025 cm; emitter spacing, 30 cm; rate of 1.89 liter per 30.5 meter per minute) was placed on the soil surface at 10 cm from the bed center and covered with black polyethylene mulch (Sonoco with 0.0038 cm thickness). 'Agriset 761 ' tomatoes were transplanted in the bed center on 25 Mar. 1998 and 24 Mar. 1999. Plants were spaced 0.45 m within row and staked. The volume of irrigation water applied daily at 60% of the mean daily volume of E^{pan} for previous 10 days.

Recently matured tomato leaves and soils were sampled on 5, 21 May, 2 Jun. 1998, and 5, 21 May, 30 June 1999. Above ground portion of two plants per plot were taken on 21 Apr., 5, 21 May 1998 and 1999. Tissue was dried in forced-air drier at 70^o C and ground to particle with diameter of < 0.6 mm. Total N was determined by Total Kjeldhal methods using 100 mg sample digested in H_2SO_4 and analyzed by Rapid Flow Colorimetry (Hanlon *et al*., 1994). P, K, Ca and Mg content were determined by dry-ash procedure using 500 mg sample dried in 500^o C for 10 hours, diluted in 1N HCl, and analyzed by ICPS (Inductively Couple Plasm Spectrophotometer).

Total plant and leaf S content was determined on digested tissue by turbidimetry procedure slightly modified from Jones (1995). Plant tissue of 500 mg was digested using $Mg(NO_3)_2$ solution on hot plate followed heating in muffle furnace at 500^o C for 4 hours. Sulfate reagent powder (SulfaVer®4 from HACH Co.) was used in the turbidimetry process. Sample was determined by using spectro-photometer (Spectronic-20D).

Tomato was harvested at the mature green or riper stage and graded into extra large (> 73 mm in diameter), large (64 to 73 mm), and medium (58 to 64 mm) sizes of marketable fruit (USDA, 1976). Analysis of variance of data was calculated using SAS 6.12 (SAS Institute, N.C). Orthogonal contrast were used to compare S-methods of application (preplant Vs split, preplant Vs drip, and split Vs drip), and S -source (sulfate Vs thiosulfate). Polynomial regression was used to analyzed S-rate effect (linear or quadratic).

Table 1. Treatment application in spring 1998 and 1999 study.

Treatments	S-source	Preplant	Drip
		.....…….. S (kg.ha-1)	.....……..
1	Check	0	0
2	SO_4	34 (100%)	0
3	SO_4	68 (100%)	0
4	SO_4	17 (50%)	17 (50%)
5	SO_4	34 (50%)	34 (50%)
6	S_2O_3	17 (50%)	17 (50%)
7	S_2O_3	34 (50%)	34 (50%)
8	SO_4	0	34 (100%)
9	SO_4	0	68 (100%)

Split = 50% preplant + 50% drip (treatments 4,5,6,7)

RESULTS AND DISCUSSION

Plant growth

Tomato growth was not influenced significantly by the methods of applications and source of S at all sampling times in both seasons (Table 2 and 3). However, tomato growth was significantly influenced by S rate in spring 1999. Sulfur deficiency symptoms were first observed in younger leaves at 4 weeks after transplanting (WAT) on the plants grown with no S application. As the growing period progressed, these visible symptom become more pronounced and spread to the lower leaf and finally reduced plant size.

By 21 Apr. 1999, approximately three weeks after transplanting, plants were quadratically larger with an increase in the rate of S applied to 68 kg S $\cdot ha^{-1}$. At the second and third sampling, plants were also largest with the largest S rate, but the response to S rate was linear. The effect of S rate on plant growth was not significant in spring 1998, however plant dry weights were larger than in spring 1999.

Table 2. Effect of S rate, source, and methods of application on tomato plant height in spring 1998 and 999

Treatment	Plant height (cm)					
	21-Apr		5-May		21-May	
	1998	1999	1998	1999	1998	1999
RATE (kg S.ha-1)						
0	21.0	21	58	47	76.0	55.0
34	21.0	27	67	55	81.0	63.0
68	22.0	27	68	59	81.0	66.0
	NS	Q**	Q**	L**	L**	L**
METHODS						
Pre	22	27	66	57	83	65
Split	22	27	68	57	82	64
Drip	22	27	68	60	81	64
Pre Vs Split	NS	NS	NS	NS	NS	NS
Pre Vs Drip	NS	NS	NS	NS	NS	NS
Split Vs Drip	NS	NS	NS	NS	NS	NS
SOURCE						
Sulfate	22	27	67	57	82	64
Thiosulfate	22	28	67	57	82	65
Sulfate Vs Thio	NS	NS	NS	NS	NS	NS

*, ** = Significant at 0.05 and 0.01 probability level, respectively, and NS = Not significant at P>0.05, L = linear, Q = quadratic

Table 3. Effect of S rate, source, and methods of application on tomato plant weight in spring 1998 and 1999

Treatment	Plant weight (g/2 plants)				
	21-Apr		5 May	21-May	
	1998	1999	1999	1998	1999
RATE (kg S.ha-1)					
0	31.6	14.6	68.2	196.0	129.0
34	39.8	25.2	93.3	200.3	167.4
68	41.6	24.8	107.1	195.5	178.0
	NS	Q**	L**	NS	L**
METHODS					
Pre	41.0	24.3	101.8	201.0	191.7
Split	41.6	24.7	97.9	197.0	162.3
Drip	38.4	26.3	103.3	196.5	174.5
Pre Vs Split	NS	NS	NS	NS	NS
Pre Vs Drip	NS	NS	NS	NS	NS
Split Vs Drip	NS	NS	NS	NS	NS
SOURCE					
Sulfate	40.4	24.3	100.3	202.0	177.0
Thiosulfate	41.5	27.0	100.0	185.5	159.8
Sulfate Vs Thio	NS	NS	NS	NS	NS

*, ** = Significant at 0.05 and 0.01 probability level, respectively, and NS = Not significant at P>0.05, L = linear, Q = quadratic

Fruit yield

Fruit yield was not influenced by S methods of application. There were not significant effect among preplant, split, and drip application of S on total marketable, extra large, large, and medium fruit size in both season, except on medium fruit size in spring 1998 (Table 4). Fruit yield also was not influenced by S source of sulfate and thiosulfate application. In spring 1998, S rate had no effect on total marketable yield although S deficiency symptom observed in the plant growth with no S application. In the spring 1999, however, a significant response to S rate was obtained. Total marketable yield increased linearly from 17.9 tons.ha^{-1} to 48.1 tons.ha^{-1} with application of 0 kg S.ha^{-1} to 68 kg S.ha^{-1}, respectively. However total marketable yield in spring 1999 was lower than in spring 1998.

Table 4. Effect of S rate on tomato total marketable yield in spring 1998 and 1999

Treatment	Marketable yield (tons.ha-1)							
	Medium		Large		Ex-large		Total	
	1998	1999	1998	1999	1998	1999	1998	1999
RATE (kg S.ha-1)								
0	10.6	2.9	23.1	8.6	27.7	6.5	61.3	17.9
34	19.0	6.7	24.6	17.6	18.9	15.8	62.4	40.2
68	20.7	6.9	25.2	21.9	17.7	19.3	63.5	48.1
	Q**	Q*	NS	L**	Q*	L**	NS	L**
METHODS								
Pre	18.8	6.5	26.1	21.2	20.3	18.2	65.3	45.8
Split	19.2	6.6	24.1	19.6	18.5	18.0	61.8	44.3
Drip	22.1	7.5	25.2	18.6	15.8	15.9	63.1	42.0
Pre Vs Split	NS	NS	NS	NS	NS	NS	NS	NS
Pre Vs Drip	*	NS	NS	NS	NS	NS	NS	NS
Split Vs Drip	*	NS	NS	NS	NS	NS	NS	NS
SOURCE								
Sulfate	19.9	6.9	24.8	19.0	18.5	16.4	63.2	42.2
Thiosulfate	19.7	6.5	25.1	22.1	17.6	21.1	62.4	49.7
Sulfate Vs Thio	NS	NS	NS	NS	NS	NS	NS	NS

*, ** = Significant at 0.05 and 0.01 probability level, respectively, and NS = Not significant at P>0.05, L = linear, Q = quadratic

Plant S Concentration

Total S concentration in leaf and plant tissue increased linearly in response to S rate application of 0 kg S.ha^{-1} to 68 kg S.ha^{-1} at all sampling time in both season, except increased quadraticaly at 2 Jun. 1999. Total leaf S concentrations were lower than in the whole plant tissue (Table 5). Sulfur deficiency symptom observed on the plant grown with no S application could be attributed to S concentration in the leaf. With no S application, leaf S concentration ranged between 0.12 to 0.19% dry weight at all sampling time. In previous work with greenhouse-grown tomatoes, Cerda *et al*. (1984) reported S deficiency symptom occurs when leaf S concentration was less than 0.18% dry weight, also Hu *et al*. (1991) reported on pecan when leaf S concentration approximately 0.15% dry weight.

In spring 1999 study, total marketable yield increased linearly with S application. This response could be attributed to S nutrition, due to leaf and plant S concentrations also increased linearly. With S application of 68 kg S.ha^{-1}, leaf S concentration at 5 May was 0.49 and 0.34% dry weight in 1998 and 1999, respectively. Maximum yield of greenhouse grown tomatoes associated with S leaf concentration of 0.48 to 1.2% dry weight was reported by Cerda *et al*. (1984).

Method of application influenced leaf S concentration at 21 May and 2 Jun. in both seasons, also plant S concentration at 21 Apr. and 21 May 1999 (Table 5). Leaf S concentration was greatest with 100 % S applied by drip irrigation, however, not different with 50% S applied preplant and 50% S applied by drip. The lowest leaf S concentration was obtained by 100% S applied preplant, and significantly different with drip and split application. Similar effects occurred on plant S concentration at 21 May sampling time in 1999.

Table 5. Effect of S rate, source, and methods of application on S concentration of leaf and plant in spring 1998 and 1999

Treatment	S leaf concentration (%dw)						S plant conc.(%dw)		
	21 Apr		5 May		21 May		1999		
	1998	1999	1998	1999	1998	1999	21 Apr	5 May	21 May
RATE (kg S.ha-1)									
0	0.19	0.18	0.15	0.12	0.19	0.17	0.22	0.17	0.25
34	0.36	0.28	0.26	0.23	0.33	0.44	0.33	0.33	0.33
68	0.49	0.34	0.35	0.31	0.47	0.52	0.39	0.42	0.37
	L**	L**	L**	L**	L**	Q**	L**	L**	L**
METHODS									
Pre	0.37	0.29	0.23	0.13	0.26	0.38	0.35	0.34	0.27
Split	0.45	0.31	0.31	0.19	0.44	0.51	0.37	0.38	0.38
Drip	0.45	0.32	0.37	0.23	0.46	0.52	0.33	0.39	0.39
Pre Vs Split	NS	NS	**	**	**	**	NS	NS	
Pre Vs Drip	NS	NS	**	**	**	**	NS	NS	
Split Vs Drip	NS	NS	*	*	NS	NS	*	NS	NS
SOURCE									
Sulfate	0.43	0.32	0.31	0.18	0.39	0.49	0.35	0.36	0.34
Thiosulfate	0.42	0.28	0.31	0.20	0.42	0.48	0.37	0.41	0.38
Sulfate Vs Thio	NS	NS	NS	NS	NS	NS	NS	NS	NS

*, ** = Significant at 0.05 and 0.01 probability level, respectively, and NS = Not significant at P>0.05, L = linear, Q = quadratic

N, P, K, Ca and Mg Concentration

Methods of application and source of S did not influence leaf and plant N, P, K, Ca, and Mg concentration in both seasons (Table 6 and 7). Concentration of P, K, Ca and Mg in the leaf at 5 May and 21 May sampling time fell within adequate range (Hochmuth, 1999). Leaf N concentration , however, fell in high level. In spring 1998, S application to 68 kg S ha^{-1} increased linearly leaf K concentration at 5 May, but quadratically at 21 May sampling time. In spring 1999, application of S reduced leaf and plant P concentration 14 and 12% at mid season, and 26 and 25% at late season sampling time, respectively.

Table 6. Effect of S rate on tomato leaf tissue N, P, K, Ca , and Mg at three sampling times in spring 1998 and 1999

S rate (kg S.ha-1)	Leaf concentration (%dry weight)									
	N		P		K		Ca		Mg	
	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
					5-May					
0	4.9	3.7	0.57	0.33	2.6	2.5	2.5	1.8	0.5	0.4
34	5.0	3.3	0.50	0.31	3.2	2.7	2.7	1.7	0.5	0.3
68	4.9	3.3	0.56	0.30	3.6	2.7	2.7	1.7	0.5	0.3
	NS	NS	NS	NS	L**	NS	NS	NS	NS	NS
					21-May					
0	4.2	3.7	0.20	0.28	1.5	2.3	1.6	1.9	0.4	0.4
34	3.9	3.3	0.21	0.24	1.8	2.3	1.7	1.9	0.4	0.4
68	3.8	3.2	0.21	0.24	1.9	2.1	1.6	1.8	0.4	0.4
	NS	NS	NS	Q**	Q**	NS	NS	NS	NS	NS
					2-Jun 1988 and 30-Jun 1999					
0	3.7	2.6	0.17	0.38	1.43	1.2	2.6	-	0.36	0.7
34	3.3	2.4	0.15	0.31	1.52	1.2	2.7	-	0.44	0.7
68	3.3	2.5	0.15	0.28	1.57	1.1	2.6	-	0.45	0.7
	Q*	NS	NS	L**	NS	NS	NS	-	Q*	NS

*, ** = Significant at 0.05 and 0.01 probability level, respectively, and NS = Not significant at P>0.05, L = linear, Q = quadratic

Table 7. Effect of S rate on tomato whole plant tissue N, P, K, Ca , and Mg at three sampling times in spring 1998 and 1999

S rate (kg S.ha-1)	Whole plant concentration (% dry weight)									
	N		P		K		Ca		Mg	
	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
					21-Apr					
0	4.7	3.9	0.52	0.36	5.26	2.9	2.1	2.5	0.6	0.6
34	5.1	4.1	0.50	0.37	5.29	3.8	2.1	2.3	0.6	0.6
68	5.1	4.0	0.49	0.38	5.21	3.9	2.0	2.3	0.7	0.6
	NS	NS	NS	NS	NS	NS	NS	L**	NS	NS
					5-May					
0	3.3	3.4	0.60	0.34	5.6	3.4	1.8	2.6	0.6	0.6
34	3.4	3.4	0.59	0.30	5.2	3.9	1.8	2.2	0.5	0.6
68	3.4	3.6	0.59	0.30	5.0	3.9	2.0	2.2	0.6	0.5
	NS	NS	NS	L**	L**	Q*	NS	Q**	NS	NS
					21-May					
0	2.4	2.35	0.43	0.28	4.3	3.0	2.0	2.6	0.6	0.7
34	2.3	2.45	0.29	0.21	3.5	3.0	2.2	2.4	0.6	0.7
68	2.4	2.35	0.33	0.21	3.4	3.0	2.3	2.4	0.6	0.7
	NS	NS	NS	Q**	NS	NS	NS	NS	NS	NS

*, ** = Significant at 0.05 and 0.01 probability level, respectively, and NS = Not significant at P>0.05, L = linear, Q = quadratic

The N/S ratio has been proposed to better express the S status in the plants than total S alone (DeBoer and Duke, 1982). Increasing S application to 68 kg S.ha^{-1} reduced N/S ratio in leaves at all sampling time (Table 8). By 5 May, at flowering stage, increasing in S application from 0 to 68 kg S.ha^{-1} reduced N/S ratio from 25.8 to 10.0 and from 20.6 to 9.7 in spring 1998 and 1999, respectively. In plant without visible N or S deficiency, a N/S ratio of ~ 9 was proposed to be near the optimum for maximum growth of pecan (*Carya illinoensis*) (Hu and Spark, 1992), ratio of 16 found in sorghum-sudangrass (*Sorghum sudanese*) (Mitchell and Blue, 1981), and ratio of 15 found in lucerne (*Medicago sativa*) (DeBoer and Duke, 1982).

There was no significant response of soil pH, P, K, Ca, and Mg to S-source, rate, and methods of application at 5 May and 21 May in both seasons (Table 9). In the end of the season, however, S application reduced soil pH ~ 0.3 unit, also application of S from 0 to 68 kg S.ha^{-1} reduced quadraticaly soil Ca and Mg concentration.

Table 8. Effect of S rate on tomato leaf N/S ratio tomato at three sampling time in spring 1998 and 1999

S rate (kg S.ha-1)	5-May		21-May		2-Jun.	
	1998	1999	1998	1999	1998	1999
0	25.8	20.6	28.0	30.8	19.5	15.3
34	13.8	11.8	15.0	14.3	10.0	5.5
68	10.0	9.7	10.9	10.7	7.0	4.8

Table 9. Effect of S rate on soil pH, Ca , Mg, K, and P at three sample times in spring 1998 and 1999

S rate (kg S.ha-1)	Soil analysis data									
	pH		Ca		Mg		K		P	
	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
			.... mg/kg soil							
					5-May					
0	6.8	6.4	442.5	518.0	43.2	41.5	51.2	49.8	94.1	91.7
34	6.7	6.4	402.9	464.3	38.2	35.5	52.7	43.9	88	83.8
68	6.8	6.4	420.3	470.9	40.6	38.0	53.5	44.4	90.8	84.7
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
					21-May					
0	6.4	6.6	420.6	559.6	46.2	43.8	48.2	42.8	92.3	95.9
34	6.3	6.5	436.7	437.7	42.5	36.5	44.0	44.0	92.2	87.0
68	6.2	6.5	448.1	540.1	47.5	39.6	47.8	47.8	93.3	91.5
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
					2 June 1998 and 30 June 1999					
0	6.4	6.8	445.0	550.8	51.5	45.0	37.1	31.5	95.4	88.3
34	6.1	6.9	454.1	583.7	49.8	53.8	39.3	23.4	93.5	87.6
68	6.2	6.5	449.7	499.9	52.0	42.2	34.4	28.1	94.1	84.7
	Q*	Q*	NS	Q*	NS	Q*	NS	NS	NS	NS

*, ** = Significant at 0.05 and 0.01 probability level, respectively, and NS = Not significant at P>0.05, L = linear, Q = quadratic

CONCLUSIONS

In conclusion, with polyethylene -mulched and drip irrigation in Florida sandy soil, tomato growth and yield can be increased by S application. The S deficiency symptom was pronounced when leaf S content less than 0.19% dry weight and N/S ratio more than 25.8. Tomato leaf S analysis at flowering stage (4 to 6 weeks after transplanting) can be used to diagnosis evaluation of the S status of tomato because at this growth stage it still possible to correct or alleviate S deficiency problem.

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