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Effect of Drip Irrigation and Nitrogen, Phosphorus, and Potassium Applications on Tomato Yield

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The state of Florida ranks second in the United States in area planted and harvested for fresh market tomatoes, with a total of 30,000 acres planted and 29,000 acres harvested in 2012. The majority of Florida's tomato production is grown in sandy soils with low organic matter and clay content, resulting in low water and nutrient holding capacities. A study was conducted to find the optimum tomato fertilization rate with drip irrigation on Immokalee fine sand soil in southwest Florida. The nutrient treatments were: 1) no fertigation (bottom mix only); 2) 150 pounds per acre (lb/acre) of N, 22.5 lb/acre of P_2O_5, 125 lb/acre of K_2O; 3) 250 lb/acre of N, 32.5 lb/acre of P_2O_5, 225 lb/acre of K_2O; 4) 350 lb/acre of N, 42.5 lb/acre of P_2O_5, 325 lb/acre of K_2O; and 5) 450 lb/acre of N, 52.5 lb/acre of P_2O_5, 425 lb/acre of K_2O. Fertigation was provided twice a week in an experiment on tomato-planted beds in Fall 2013. Yields in 25-pound boxes per acre were 823, 1301, 1920, 2176, and 2190 for treatments 1 through 5, respectively. The yield results indicate that an increase in fertilizer application more than the University of Florida, Institute of Food and Agricultural Sciences recommendation rate doesn't guarantee an increase in the tomato yields.

Florida ranks second in the area planted and harvested for fresh tomatoes compared with all U.S. states. For 2012, the area planted was 30,000 acres and 29,000 acres were harvested (USDA, 2013).

The largest portion of Florida's tomato production area is characterized by sandy soils (Dukes et al., 2006). Major factors affecting the fertility of these soils include the amount of rainfall received annually and high temperatures, both weather events occurring the majority of the year (McAvoy and Ozores-Hampton, 2011). Sandy soils of south Florida are characterized by low organic matter content (McAvoy and Ozores-Hampton, 2011). Because of the poor fertility of this soil, growers have to apply large quantities of fertilizers to supply all nutrient requirements in order to obtain optimum yields (McAvoy and Ozores-Hampton, 2011).

For a mineral soil in Florida very low in phosphorus (P) and potassium (K) the recommendations are: 200 nitrogen (N), 150 P_2O_5 and 225 K_2O lbs/acre/crop season (Olson et al., 2012).

A study by Bryan and et al., (1975), found that drip irrigation was more efficient in supplying water more uniformly to the soil and allowing more constant soil moisture. Drip irrigation presents a trend in Florida when compared with overhead systems. In the same study (Bryan and et al., 1975), when tomato plants that were fertilized through drip irrigation were compared with tomatoes fertilized with overhead fertilizer, the drip irrigated fruit was larger and the yields higher. The drip irrigation system obtained better yield using 1/3 less water compared with the overhead system.

The objectives of this study was to determine the effect of fertigation N, P and K amounts above and below recommended levels through drip fertigation on 1) biomass accumulation and yield and 2) estimated nutrient uptake in Florida on sandy soil.

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Materials and Methods

Experimental location, type of soil and climate. The study was conducted in Fall 2013 on tomato (*Lycopersicon esculentum* Mill.),variety RFT 6153 at the University of Florida, Southwest Florida Research and Education Center (SWFREC), in Immokalee, FL, (latitude 26.42°N; longitude 81.43°W, 10.41 m above sea level). The soil series dominating in the site was Immokalee fine sand (sandy, siliceous, hyperthermic, Arenic Haplaquods), mechanically leveled, poorly drained due to presence of a Spodic horizon, and the parental material is sandy marine deposits (Obreza and Collins, 2008; USDA, 1990). Average rainfall at Immokalee for the most recient 10 years from 2003–13 (August to December) was 3.81 inches <http://fawn.ifas.ufl.edu/>.

Experimental design and fertigation treatments. The experimental design was a randomized complete-block design, with four repetitions of each treatment. The tomatoes were planted on 16 Sept. 2013 with first harvest on 3 Dec. 2013. Three beds per plot were built with 6 ft between bed centers, a height of 8 inches and a length of 30 ft. The beds were fertilized with 50 lb/acre of N, 12.5 lb/acre of P_2O_5, 25 lb/acre of K_2O of soluble 16-4-8 as a bottom mix. Two drip lines were installed (one for irrigation and one for the fertigation), and fumigated with methyl bromide at 160 lb/acre. After six weeks the plants were transplanted into the beds in a single row next to the irrigation and fertigation lines. The fertigation treatments were as follows: 1) no fertigation (bottom mix only); 2) 150 lb/acre of N, 22.5 lb/acre of P_2O_5; 125 lb/acre of K_2O; 3) 250 lb/acre of N, 32.5 lb/acre of P_2O_5, 225 lb/acre of K_2O; 4) 350 lb/acre of N, 42.5 lb/acre of P_2O_5, 325 lb/acre of K_2O; and 5) 450 lb/acre of N, 52.5 lb/acre P_2O_5, 425 lb/acre of K_2O. As a result of several rain events that occurred after the beds were made, the field was flooded and a portion of the fertilizer (nutrients), was heavily leached. Because of this, after the rain events it was decided that N rates equal to

0%, 50%, 100%, 150%, and 200% of UF/IFAS recommendations were applied through the fertigation as treatments 1–5, respectively. Thus, treatment 3 is 50 lb/acre more of N than the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS) recommendation rate. The plots were fertigated twice a week and the amount of fertilizer applied varied based on the week after transplanting using the UF/IFAS recommendation schedule of the lbs/ac/day for drip irrigated tomatoes (Olson et al., 2012).

Tomato yield estimation. The first harvest was 91 days after transplanting (DAT). Following the first harvest, the second and third harvest were one week apart. At the time of harvest the tomatoes were categorized by size and color according to USDA (1997).

Estimation of plant nutrient uptake and nutrient use efficiency. In order to estimate the nutrient concentration in the plant, biomass samplings were taken 12 weeks after transplanting. A representative plant from the middle row was taken from each plot and separated into leaves, stems, and fruits. The samples were weighed fresh and then placed into an oven at 149 °F for three days for the leaf samples, and seven days for the stems and fruits until constant dry weight. The samples were analyzed for N, P, and K. The nutrient use efficiency (NUE) for N was calculated by the plants nutrient uptake divided by the total amount of N applied for the crop season.

Statistical analysis. For analyzing the data we used PROC GLM procedure (SAS, 2012), in order to determine the treatment effects on fruit, stems and leaves nutrients accumulation and yields. When the F-value was significant, means were separated using the Duncan's multiple range test with a *P*-value of 0.05.

Results and Discussion

Tomato yield. A significant response to fertilizer application rate was observed $P \leq 0.05$. There were differences between treatments in the marketable yield per harvest and for the total harvest (Table 1) where treatments 1, 2, and 3 were 37%, 59%, and 87% of treatment 5, respectively (Table 1). Overall, yields of treatments 3, 4, and 5 were not statistically different. In the first harvest, there were not significant differences between treatments. Yields for the second, third (all the size categories combined) and total harvest (the three harvests together), treatments 3, 4, and 5 were similar but significantly different from treatments 1 and 2. The marketable yields for the total harvest for treatment 3, 4, and 5 were greater than the average yield per acre reported for the Florida Department of Agriculture and Consumer Services 33000 lb/acre fresh market in 2012 (Florida Department of Agriculture and Consumer Services, 2013). Treatment 1 and 2 were below the average yield. The number of 25-pound boxes per acre for treatment 3, 4, and 5 (Table 2) exceeded the average number of boxes/acre (1320 boxes) (Florida Dept. of Agriculture and Consumer Services, 2012).

Most growers apply more fertilizer than the recommended rate in order to avoid the risk of yield reductions (Zotarelli et al., 2009), but the yield results indicate that an increase in fertilizer application more than the UF/IFAS recommendation rate does not guarantee an increase in tomato yields. Zotarelli et al. (2009) found, in a study conducted on tomatoes with drip irrigation for three seasons, which an application of more than 157 lb/acre of N did not result in an increase in yields. In their study, the range (for the three spring seasons) of the marketable yield for N-rate of 196 lb/acre and 294 lb/acre and surface irrigation was 24,538 to 76,471 lb/acre was similar to the yield measured in this study for treatment 3 and 4 was 47,850 to 54,234 lb/acre.

Table 1. Mean total marketable yield lb/acre. Immokalee, FL, Fall 2013.

Treatment	lb/acre First harvest	Second harvest	Third harvest	Total harvest
1	5590	3295 C[z]	8023 B	20512 C
2	10705	12559 B	9149 B	32412 B
3	8610	20015 A	19223 A	47850 A
4	12009	22660 A	19562 A	54234 A
5	13217	21905 A	19450 A	54573 A
P-value	ns	**	***	***

[z]Means within in the same column with different letters are significantly different using Duncan's multiple range test, $P \leq 0.05$.
ns Not significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$.

Table 2. Mean number of boxes[z] per acre. Immokalee, FL, Fall 2013.

Treatment	boxes/acre First harvest	Second harvest	Third harvest	Total harvest
1	240	261 C[y]	322 B	823 C
2	430	504 B	367 B	1301 B
3	346	803 A	772 A	1921 A
4	482	910 A	785 A	2177 A
5	531	879 A	781 A	2190 A
P-value	ns	***	***	***

[z]Boxes of 25 pounds each.
[y]Means within in the same column with different letters are significantly different using Duncan's multiple range test, $P \leq 0.05$.
ns Not significant at $P < 0.05$; *** significant at $P < 0.001$.

Biomass and nutrient accumulation on leaves, stems and fruit. The dry weight of leaves (lb/acre) for treatments 3, 4 and 5 were similar, but different from treatments 1 and 2. For the Leaf N content (lb/acre) there were significant differences between treatments (Table 3). For P and K content (lb/acre) treatment 3, 4, and 5 were similar but differed for treatment 1 and 2. Leaf N and K percent of nutrient in the biomass samples collected 12 weeks after transplanting there were significant differences between treatments (Table 3). However, no differences were found between treatments for P leaf concentrations.

There were no significant differences between treatments for the percent of K in the stems. However, there were significant differences between treatments for stem N concentrations (Table 4). For the stem dry weight (lb/acre) and the N content (lb/acre) there were differences between treatments (Table 4). No differences were found for the P content (lb/acre) between treatments. For N content (lb/acre) in the stem overall treatments 3, 4, and 5 were similar but differed from treatments 1 and 2.

For fruit nutrient percentage and nutrient content (lb/acre) at 12 weeks after transplanting there were no differences among treatments for K or for fruit dry weight (lb/acre). For N and P there were differences found between treatments (Table 5).

The range of shoot dry weight results for this study for treatment 3 and 4 were greater than the ones obtained by Zotarelli et al. (2009) for their N-rate 196 lb/acre, 294 lb/acre and surface drip irrigation. Fruit dry weight for the present study for treatment 3 and 4, agree with the range of results obtained by Zotarelli et al. (2009) for their N-rate 196 lb/acre, 294 lb/acre and surface drip irrigation. Shoot N-accumulation (lb/acre) our range for treatment 3 and 4 was slightly higher than the one obtained for N-rate 196 lb/acre, 294 lb/acre and surface drip irrigation by Zotarelli et al. (2009). Shoot P accumulation in our study and Zotarelli et al. (2009) agreed, but the range of P in the fruit for our treatments 3 and 4 were lower than Zotarelli et al. (2009).

Scholberg et al. (2000) reported in a study conducted in Gainesville with drip irrigated tomatoes, for measurements collected 91 days (13 weeks) after transplanting with an application of 300 lb/acre of N, that the total dry matter was 1.19 ± 0.13 lb/plant and for the treatment that did not receive any N-fertilizer application the value was 0.37 ± 0.007 lb/plant. In the present study, it was found that for treatment 4 (350 lb/acre N), the dry matter per plant 12 weeks after transplanting was in the range of 1.11 lb/plant and for treatment 1, the dry matter was 0.68 lb/plant. It can be observed that our results agree with their results for the treatment that received an application of 350 lb/acre of N. For the treatment that did not receive any fertilizer, our lb/plant were greater than their results.

The NUE for N for treatment 1, was higher than 40% and for treatment 2, 3, and 4 was closer to 40% (Table 6). For treatment 5 the NUE was lower compared with the rest so it can be observed that the application of more fertilizer does not result in better NUE. For the calculation of the NUE it was not take in

Table 3. Biomass mean percentage of nutrient in tomato leaves and mean nutrient content lb/acre 12 weeks after transplanting. Immokalee, FL, Fall 2013.

	Mean percentage of nutrient on tomato leaves				Mean leaf nutrient content		
Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Leaf dry wt (lb/acre)	Nitrogen (lb/acre)	Phosphorus (lb/acre)	Potassium (lb/acre)
1	1.41 C[z]	0.64	1.59 B	752.5 B	10.47 B	5.37 B	11.82 B
2	2.35 C	0.69	1.87 B	972.7 B	22.60 B	6.73 B	17.96 B
3	2.74 B	0.65	3.03 A	1524.5 A	42.38 A	9.80 A	48.28 A
4	3.51 B	0.61	3.17 A	1580.0 A	55.85 A	9.43 A	50.73 A
5	3.63 A	0.62	3.28 A	1516.5 A	55.21 A	9.31 A	49.93 A
P-value	***	ns	***	***	***	**	***

[z]Means within in the same column with different letters are significantly different using Duncan's multiple range test, $P \leq 0.05$.
ns Not significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$.

Table 4. Biomass mean percentage of nutrient in tomato stems and mean nutrient content lb/acre, 12 weeks after transplanting. Immokalee, FL, Fall 2013.

	Mean percentage of nutrient on tomato stems				Mean stem nutrient content		
Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Stem dry wt (lb/acre)	Nitrogen (lb/acre)	Phosphorus (lb/acre)	Potassium (lb/acre)
1	0.69 C[z]	0.77	2.39	775.4 C	4.35 B	5.86	17.06
2	0.75 C	0.64	2.04	985.5 C	7.39 B	6.35	20.48
3	1.38 B	0.57	2.69	1227.4 A	16.87 A	6.90	33.14
4	1.53 B	0.56	3.18	1047.2 AB	17.11 A	6.68	29.63
5	2.18 A	0.53	3.33	1092.3 AB	20.98 A	5.80	36.44
P-value	***	ns	ns	**	***	ns	ns

[z]Means within in the same column with different letters are significantly different using Duncan's multiple range test, $P \leq 0.05$.
ns Not significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$.

Table 5. Biomass mean percentage of nutrient in tomato fruit and mean nutrient content (lb/acre), 12 weeks after transplanting. Immokalee, FL, Fall 2013.

	Mean percentage of nutrient on tomato fruit				Mean fruit nutrient content		
Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Fruit dry wt (lb/acre)	Nitrogen (lb/acre)	Phosphorus (lb/acre)	Potassium (lb/acre)
1	2.53 D[z]	0.99 C	6.39	1054.8	24.26 C	9.51 C	69.99
2	3.73 C	0.97 C	6.29	1119.4	41.35 B	10.72 C	70.68
3	4.39 BC	1.12 B	6.60	1336.2	58.34 A	14.96 B	87.96
4	4.62 BA	1.09 B	6.00	1399.6	64.76 A	15.29 B	84.56
5	5.24 A	1.45 A	6.80	1311.3	68.76 A	18.84 A	88.17
P-value	***	***	ns	ns	***	***	ns

[z] Means within in the same column with different letters are significantly different using Duncan's multiple range test, $P \leq 0.05$.
ns Not significant at $P < 0.05$; *** Significant at $P < 0.001$.

Table 6. Fertilizer use efficiency for nitrogen. Sampling 12 weeks after transplanting. Immokalee, FL, Fall 2013.

	Percentage of fertilizer use efficiency
Treatment	Nitrogen
1	59
2	38
3	38
4	35
5	28

account the amount of nutrient (N) that was already in the soil.

The low N NUE for treatment 5 can be a result of greater amounts of the fertilizer nutrients contributing to nutrients leaching out of the root zone.

Conclusions

More application of fertilizer in treatment 4 and 5 did not result in statistically different biomass and yield compared with treatment 3 (similar to UF/IFAS recommendation), thus indicating that the application of more fertilizer did not result in more yield. The NUE for treatment 5 was lower compared with the rest, potentially increasing the amount of fertilizer nutrients leached below the root zone. Therefore, the current UF/IFAS recommendation is sufficient for optimum production under soil and environmental conditions in southwest Florida.

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