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Effect of Drip Irrigation and Nitrogen, Phosphorus and Potassium Application Rates on Tomato Biomass Accumulation, Nutrient Content, Yield, and Soil Nutrient Status

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Abstract

The majority of Florida's tomatoes are grown on sandy soils, having low water and nutrient holding capacities. Tomato growers have to supply large quantities of fertilizer in order to supply all the nutrients required for satisfactory growth. Drip irrigation provides many advantages including a reduction of water use and efficient fertilizer management compared with other irrigation systems. Studies of fertigated tomato grown on plastic mulch covered beds in fall 2013, spring 2014 and fall 2014 were conducted to quantify the effect of different fertigation rates on tomato biomass accumulation and fruit yields; and the measurement of N, P and K concentrations and distribution pattern in the soil at different sampling positions and depths during the whole season in Florida on sandy soils. The experimental results indicated, the application of more fertilizer application than the recommended dose does not increase the tomato fruit yield significantly while it had led to luxurious consumption of nutrients and excessive biomass accumulation by tomato plants Drip fertigation kept the nutrients at optimum concentration in the crop root zone within the top 0 – 30-cm soil depth. Additional research is needed to quantify nutrient leaching below the crop root zone.

Keywords: Leaching; Fertilizer; Nutrients

Introduction

The state of Florida ranked first in the US in tomato (*Solanum lycopersicum* L.) production area planted (13,350 ha) and harvested (13,030 acres) for fresh market in 2015 (USDA, 2016). Florida. Total fresh tomato production area for the US was 38,500 ha planted and 37, 300 ha harvested. Tomatoes are grown on sandy soils in Florida. As a result of low organic matter and large porosity, the sandy soils in Florida have low cation exchange and water holding capacities, requiring growers to apply large quantities of fertilizer to supply all the nutrients that the crop needs for optimum yields [1]. Tomato has a high market value and growers usually apply more fertilizer than the crop requires avoiding the risk of yield reductions [2]. The University of Florida, Institute for Food and Agricultural Sciences (UF/IFAS) fertilizer recommendations for a crop under irrigation on a mineral soil in Florida testing low in phosphorus (P) and potassium (K) are: 224 nitrogen (N), 168 P_2O_5 and 252 K_2O kg/ha/crop season [3]. It is important to apply nutrients and water to the crop in the right amount and at the right time because high fertilizer application, low nutrient extraction and high quantities of water through irrigation and rainfall, can consequently result in N leaching [2,4,5].

With the low water holding capacity of Florida sandy soils, another part of tomato production vital for high yields is irrigation. The most common irrigation system used in south Florida for tomato production is seepage [6]. Irrigation application efficiency can be affected by many aspects such as soil characteristics, climate conditions, method of application, the kind and stage of crop among others [6]. Seepage irrigation has low water application efficiencies (25 to 60%) compared with 80% to 95% for drip irrigation [6,7].

Drip irrigation is known for reduced water use, improved nutrient management by fertigation, enhanced water distribution, improved nutrient uptake and simplified scheduling the irrigation of extensive areas of production [8-11].

Roots play important roles including absorption of nutrients and moisture [12]. If the development of the root system is affected by improper water and nutrient management, the nutrient, water and salt concentration and distribution will be affected in the plant [12]. Thus, growers must be concerned about nutrient applications, because the lack or excess of nutrients can make large difference in yields. Consequently, it is important to evaluate the efficacy of fertigation rates for tomato production under drip irrigation system to maximize nutrient and water use efficiency, and obtain improved yields in Florida. Fertigaiton rates can vary during the growing season because of unforeseen errors in scheduling such as fertigation missed during heavy rainfall, failures in pumping equipment, delays in fertilizer delivery, and miscommunications among field staff (personal communications with growers). Considering all these points, the current study had following two main objectives: 1) The effect of different fertigation rates on tomato harvest index; and 2) Distribution pattern of fertigation in different plant parts and the soil layers.

Materials and Methods

Experimental location and experimental design

The experiments were conducted at University of Florida, Southwest Florida Research and Education Center (SWFREC) in

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Immokalee, Florida (Latitude 26.42° N and Longitude 81.43° W, at 10.41 m above sea level). The soil was Immokalee fine sand classified as sandy, siliceous, hyperthermic, Arenic Haplaquods [13]. The three experiments were conducted with tomato grown on raised plastic mulch covered beds in a randomized complete block design, with 4 replications of each fertigation treatment applied twice per week. Three experiments were conducted in fall 2013, spring 2014, and fall 2014. Three beds, 20 cm high and 914 cm long, were constructed per plot with a spacing of 183 cm between bed centers in the fall 2013. The bed for the spring and fall 2014 seasons were 20 cm high and 1524 cm long with 183 cm between bed centers. Two drip irrigation lines (30.5 cm emitters spacing, Jain Irrigation Inc.) were installed in each bed (one drip line for irrigation and the other for fertigation). The beds were fumigated with methyl bromide at 180 kg ha^{-1} in fall 2013. Approximately 67 kg ha^{-1} of Pic-Chlor60 was applied to fumigate the beds in the spring and fall 2014 seasons. There was no herbicide applied in the beds in any of the fall seasons, however in the spring 2014 season 0.77 kg ha^{-1} of Dual Magnum was applied pre-plant as an herbicide. The tomato plants were transplanted in a single row next to the fertigation and irrigation lines. The varieties used were RFT 6153 (Syngenta, USA) in fall 2013 and Tygress (Monsanto, USA) for the spring and fall 2014 seasons.

Fertilizer rates

All the plots were fertigated twice a week. The quantity of fertilizer applied varied with plant growth phase based on week after transplanting (WAT) as specified in Table 1. Total N and K fertilizer rates were 25%, 50%, 100%, 150% and 200% of UF/IFAS recommendations. In all seasons, 25% of the UF/IFAS recommended N rate, 12.5% of recommended K rate, and 50% of the recommended P rate were incorporated in the beds with 56 kg ha^{-1} N, 14 kg ha^{-1} P_2O_5 and 28 kg ha^{-1} K_2O as soluble fertilizer. All beds were irrigated with a surface drip irrigation system under plastic mulch cover. As a result of several rain events after the beds were formed (recorded rainfall was 9.3 cm for 2 days after bedding) but prior to planting in the fall season 2013, the field was flooded and a large amount of nutrient was assumed to be leached from the beds. As a result of the flooding, N, P and K rates equal to the target total season fertilizer amounts were applied to each treatment by fertiation (Table 1).

Soil sampling

Random soil samples were collected at 12 locations across the experimental field prior to for the fall 2013, spring 2014, and fall 2014 seasons to determine the initial nutrient status of the field prior to bed formation. Soil samples were taken with a 2.5 cm auger at three depths (0-15, 15-30, and 30-45 cm) below the soil surface. After bed formation, two soil samples were taken from each treatment plot with a 2.5 cm auger at the same three depths (0-15-, 15-30-, and 30-45 cm) below the bed surface. One sample was collected 7 cm perpendicular to the fertigation line (position 1) and in the planted row 15.2 cm between plants (position 2). Soil samples were taken prior to initial fertigation and once a month to harvest. In order to prevent transformation of N from NH_4 to NO_3, the samples were taken and stored in a cooler containing ice. The samples were kept in a freezer at <4°C until analysis.

Soil nitrogen, phosphorus and potassium analysis

Ammonium-N (NH_4^+-N) and nitrate (NO_3^-_N) determination was conducted using 2 M KCl extraction method [14] from each soil sample (wet), 5.0 g were weighed and placed into a centrifuge tube. Forty ml of 2 M KCl solution was added to the centrifuge tube, capped and then shaken for 30 min at low speed. The solution was allowed to settle for 20 to 30 min, and filtered (Whatman paper number 1, 90 mm). The filtrate was poured in plastic vials and stored in a freezer at <4°C until analysis. After the solutions were thawed, NH_4^+-N and NO_3^--N analysis was performed using a Flow Analyzer (QuichChem 8500, Lachat Co.) at 660 nm and 520 nm, respectively. The results were expressed on an oven-dry soil basis by determining the soil moisture content by gravimetric method at time of analysis.

The K and P analysis was conducted using Mehlich-3 (M-3) soil extraction [15]. Approximately 2.5 g of soil oven-dried for 24 h at 105°C was weighed and placed into centrifuge tubes and 25 ml of M-3 solution was added. The samples were capped and shaken for 5 min at a high speed. The sample solution was allowed to settle for 20 to 30 min., then, the extracts were filtered (Whatman paper number 1, 90 mm). The filtrate was stored in plastic sample vials in a refrigerator. Analysis for M-3 P and K was conducted by Inductively Coupled Plasma (ICP)-Optimal Emission Spectrometer Optima 7000DV (Perkin Elmer Co.) at 213.6 nm and 766.5 nm for P and K, respectively.

Fertilization rate	Leaf dry weight	Stem dry weight	Fruit dry weight
	(kg ha^{-1})		
	Fall 2013		
1 [z]	952B [y]	870C	1180
2	1092B	1106BC	1252
3	1711A	1378A	1495
4	1721A	1175BA	1653
5	1702A	1226BA	1467
p-value	**	**	NS
	Spring 2014		
1 [x]	151C	142C	x
2	387B	341B	x
3	609A	612A	x
4	596A	599A	x
5	672A	600A	x
p-value	***	***	x
	Fall 2014		
1 [x]	926	710	344
2	1017	746	792
3	1084	821	935
4	1122	772	888
5	1145	704	1003
p-value	NS	NS	NS

[z] Fertilization rate: 1 = no fertigation (bottom mix only); 2 = 168 kg N ha^{-1}, 25 kg P_2O_5 ha^{-1}, 140 kg K_2O ha^{-1}; 3 = 280 kg N ha^{-1}, 36 kg P_2O_5 ha^{-1}, 253 kg K_2O ha^{-1}; 4 = 393 kg N ha^{-1} , 48kg P_2O_5 ha^{-1}, 365 kg K_2O ha^{-1}; and 5 = 505 kg N ha^{-1}, 59 kg P_2O_5 ha^{-1}, 477 kg K_2O ha^{-1}.

[y] Means in the same column and same season with different letters are significantly different using Duncan's multiple range test.

[x] Fertilization rate: 1 = no fertigation (bottom mix only); 2 = 112 kg N ha^{-1}, 20 kg P_2O_5 ha^{-1}, 84 kg K_2O ha^{-1}; 3 = 225 kg N ha^{-1}, 31 kg P_2O_5 ha^{-1}, 196 kg K_2O ha^{-1}; 4 = 337 kg N ha^{-1} ,42 kg P_2O_5 ha^{-1}, 309 kg K_2O ha^{-1}; 5 = 449 kg N ha^{-1} ,53 kg P_2O_5 ha^{-1}, 421 kg K_2O ha^{-1}.

[x] There were not fruit sample for that sampling.

NS = Nonsignificant at $P < 0.05$; **, ***Significant at $P < 0.01$ and $P < 0.001$, respectively.

Table 1: Mean dry weight of leaves, stems and fruit, 12 weeks after transplanting (WAT) in fall 2013, 11 WAT spring 2014 and 13 WAT fall 2014.

Biomass sampling and analysis

Crop biomass were collected at 5, 9 and 12 WAT in fall 2013; at 5, 9; 11 WAT in Spring 2014 and at 4, 8 and 13 WAT in fall 2014. One representative plant per plot was sampled for biomass determination. The samples were separated into leaf, stem and fruit sub-samples, weighed fresh and then placed in an oven at 65 °C for three days (leaf samples) and one week (stem and fruit samples). The dry weight was determined and each sample was run through a stainless steel 20 mesh sieve and later through a 60 mesh sieve [16]. Total N in the leaves, fruit and stems were analyzed according to methods described by Hanlon et al. [16] using the C/N Analyzer NA2500 (Thermoquest CE Instruments). The determination of total tissue P and K contents was conducted by dry ash digestion method followed by Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES) analysis [16,17].

Tomato harvest and yield

Fruits were harvested three times in each season; 11, 12 and 13 WAT for fall 2013, 10, 11 and 12 WAT spring 2014 and 11, 13 and 16 WAT for fall 2014 seasons. The fruit harvested was divided into marketable color (i.e. green and red) and size (i.e., extra-large, large, medium, small and un-marketable culls) according to USDA standards (1997).

Statistical analysis

The PROC GLM procedure from the SAS program [18] was used for determining treatment effects on nutrient concentration, biomass, fruit yields and soil nutrient concentration. In the cases when the F-value was significant, a second analysis was done using Duncan's multiple range tests at a P-value of 0.05.

Results and Discussion

Biomass accumulation and nutrient concentration

Tomato is well known for its response to fertilizer application [4,19]. The common methods used for the application of the fertilizers (such as broadcasting, and banding) are not efficient, unlike fertigation where the nutrients are applied directly to the root zone and fertilizer use efficiency can be enhanced [19]. Significant differences were found among treatments for leaf, stem and fruit dry weight in the fall 2013 season indicating significantly greater biomass for treatment 3 (280 kg ha^{-1} N, 253 kg ha^{-1} K), but no significant increase in biomass at fertilizer rates greater than that rate (Table 2). In the spring 2014 season, the plants were affected by bacterial leaf spot, a severe wide-spread disease that affects tomato [20]. Yields during the spring 2014 season were limited by the disease and was lower in quality than expected for a commercial acceptable crop. Nonetheless, leaf and stem tissue biomass accumulation in the spring 2014 season (fruit data not included) increased with fertilizer rate but did not increase above the rate equal to treatment 3 (224 kg ha^{-1} N, 196 kg ha^{-1} K). In the fall 2014 season, there were no significant differences among treatments for leaves, stems and fruit dry biomass (kg ha^{-1}) (Table 2).

Concentration (%) of N in the leaves and stems increased significantly with fertilizer rates in the fall 2013 and spring 2014 seasons, and for fruit in fall 2013 and stems in fall 2014 seasons

Fertilization rate	N in the leaves	N in the stems	N in the fruit	P in the leaves	P in the stems	P in the fruit	K in the leaves	K in the stems	K in the fruit
	(%)								
	Fall 2013								
1^z	1.37D^y	0.46C	2.57D	0.62	0.75A	1.00CB	1.46B	2.19	6.26
2	2.35C	0.74C	3.73C	0.69	0.64BA	0.96C	1.86B	2.04	6.29
3	2.74BC	1.37B	4.39BC	0.64	0.56B	1.12B	3.03A	2.69	6.60
4	3.41BA	1.53BA	4.74BA	0.62	0.56B	1.09CB	3.23A	3.18	5.92
5	3.87A	1.89A	5.33A	0.61	0.47B	1.39A	3.05A	2.76	6.40
p-value	***	***	***	Ns	*	***	**	Ns	ns
	Spring 2014								
1^x	1.78C^y	1.26C	^{w}	0.11A	0.07	^{w}	0.04C	0.04D	^{w}
2	2.77B	2.02B	^{w}	0.07B	0.05	^{w}	0.26B	0.24C	^{w}
3	3.38B	2.21B	^{w}	0.07B	0.05	^{w}	0.47A	0.29CB	^{w}
4	3.74A	2.72AB	^{w}	0.06B	0.05	^{w}	0.56A	0.48AB	^{w}
5	3.87A	2.97AB	^{w}	0.05B	0.05	^{w}	0.48A	0.50A	^{w}
p-value	***	**	^{w}	***	NS	^{w}	***	**	^{w}
	Fall 2014								
1^x	2.53	1.19C	4.78	0.84A	0.49	0.92	0.46C	0.21B	3.29C
2	3.93	1.44C	5.21	0.66BC	0.38	0.90	0.76BC	0.31B	3.91BC
3	4.06	1.42C	4.20	0.58BC	0.40	0.81	0.95BC	0.50B	4.73B
4	3.76	2.03B	4.50	0.51C	0.35	0.79	1.10B	0.63B	4.79B
5	4.44	3.12A	5.05	0.69AB	0.57	0.90	2.68A	2.36A	6.11A
p-value	NS	***	NS	**	NS	NS	***	***	**

^{z} 1 = no fertigation (bottom mix only); 2 = 168 kg N ha^{-1}, 25 kg P_2O_5 ha^{-1}, 140 kg K_2O ha^{-1}; 3 = 280 kg N ha^{-1}, 36 kg P_2O_5 ha^{-1}, 253 kg K_2O ha^{-1}; 4 = 393 kg N ha^{-1}, 48 kg P_2O_5 ha^{-1}, 365 kg K_2O ha^{-1}; and 5 = 505 kg N ha^{-1}, 59 kg P_2O_5 ha^{-1}, 477 kg K_2O ha^{-1}.

^{y} Means in the same column and same season with different letters are significantly different using Duncan's multiple range test.

^{x} 1 = no fertigation (bottom mix only); 2 = 112 kg N ha^{-1}, 20 kg P_2O_5 ha^{-1}, 84 kg K_2O ha^{-1}; 3 = 225 kg N ha^{-1}, 31 kg P_2O_5 ha^{-1}, 196 kg K_2O ha^{-1}; 4 = 337 kg N ha^{-1},42 kg P_2O_5 ha^{-1}, 309 kg K_2O ha^{-1}; 5 = 449 kg N ha^{-1},53 kg P_2O_5 ha^{-1}, 421 kg K_2O ha^{-1}.

^{w} There were not fruit sample for that sampling.

NS = Nonsignificant at P < 0.05; *, **, ***Significant at P < 0.05, P <0.01 and P < 0.001, respectively.

Table 2: Mean percent of nutrient (N, P and K) in the leaves, stems and fruit at 12 weeks after transplanting (WAT) in fall 2013, 11 WAT in spring 2014 and 13 WAT in fall 2014.

(Table 3). However, similar to biomass, no significant increases in N concentrations were found above treatment 4 (393 kg ha^{-1} N in 2013 and 337 kg ha^{-1} N in 2014). Phosphorus concentrations increased in the leaves in the spring and fall 2014 seasons at the lowest P fertilizer rate. Potassium concentrations in the leaves occurred for all seasons with increased K concentrations in stems, and fruit for both seasons of 2014. Plant tissue accumulation, as expected, was a function of biomass weight and tissue concentration. Thus N, P, and K content increased significantly among treatments for all tissues with the exception of leaf N, leaf and stem P in fall 2014 (Table 4).

Nitrogen and K accumulation was greater in fruit than leaves and stems in fall 2013 while in fall 2014 N and K accumulation in fruit and leaves were similar to accumulation in stems. Hartz and Bottoms [21] made similar observations in N, though with lower N rate of 200 kg ha^{-1}. According to Hartz and Bottoms [21], the rate of tomato growth and N uptake peak during fruit setting and slow after fruit ripening begins, thus, N applications should coincide with peak requirements to prevent excessive application and leaching.

Tissue N accumulation in leaves, stems and fruits in the ranged of 27-38%, 10-16%, and 46-62% in fall 2013 and 40-48%, 12-18% and 32-46% in fall 2014, respectively. Phosphorus accumulation in leaves, stems and fruits in the ranges of 23-31%, 15-27%, and 44-56% in fall 2013 and 36-54%, 16-25% and 20-45% in fall 2014, respectively. Potassium was distributed in leaves, stems and fruit in the range of 13-31%, 9-21% and 47-75% in the two fall seasons, respectively. Thus, most potassium was allocated in the order fruit>leaves>stems across the two seasons.

Plant growth in fall 2014 was reduced by bacterial spot; therefore, increased fertilizer did not significantly increase yields. This disease can cause tremendous negative effects to the tomato plants in some cases may result in a complete loss of the crop in areas characterized for warm and humid weather these climatic conditions favor the survival of the disease [20]. The spring 2014 season of the tomato was characterize by several rain events which may have favored disease development which resulted in extremely damaged plants that did not grow well, some plants died. As a result of the bacterial spot, the production of tomato per plant was extremely low. Foliar applications of bactericide were made to control the disease but unfortunately the plants were extremely affected. The disease resulted in reduced yields for all the treatments compared with the fall 2013 and 2014 seasons, however differences in yields among treatments were observed with total harvest for treatments 3, 4 and 5 greater than treatments 1 and 2 (Table 5).

Marketable yield and number of boxes per hectare

It is important to apply the right rate of nutrients because the excessive application of fertilizer can lead to luxurious consumption [10]. Thus, the results of this study show that the application of more fertilizer than 224 kg ha-1 N for tomato grown on sandy soils under drip irrigation did not result in a significant increase in yields. However, Motis et al. [22] found no significant differences among the treatments for marketable yield when they evaluated five levels of drip- or band-applied N at 0, 25, 50, 75, and 100% applied at 224 kg ha^{-1}, 196 kg ha^{-1} K. Mixed-results in two years were obtained by researchers in Florida under seepage-irrigation where highest marketable yields were obtained with 172 and 298 kg ha^{-1} of N in 2007 and 2008, respectively [23].

Fertilization rate	N in the leaves	N in the stems	N in the fruit	P in the leaves	P in the stems	P in the fruit	K in the leaves	K in the stems	K in the fruit
	(kg ha^{-1})								
	Fall 2013								
1 y	14.95C x	5.39B	33.51C	6.12B	6.71	13.06CB	17.27C	19.92	92.46
2	25.37CB	8.30B	46.27BC	7.56B	7.13	12.00C	20.16BC	22.99	79.09
3	40.68B	19.26A	62.28BA	9.63A	7.89	16.23CB	43.67BA	36.66	93.41
4	61.98A	21.33A	73.01A	10.85A	7.50	16.74B	58.94A	42.35	91.61
5	65.42A	23.55A	81.35A	10.56A	5.80	21.49A	59.44A	35.85	101.46
p-value	**	**	*	**	NS	**	*	NS	NS
	Spring 2014								
1 w	2.92C x	1.62C	v	0.18C	0.10B	v	0.01B	0.06C	v
2	10.81B	6.87B	v	0.27BC	0.16B	v	1.00B	0.82BC	v
3	20.74A	13.49A	v	0.41A	0.32A	v	2.92A	1.84AB	v
4	21.80A	15.81A	v	0.38A	0.33A	v	3.36A	2.78A	v
5	23.82A	17.17A	v	0.32AB	0.30A	v	3.05A	2.89A	v
p-value	***	***	v	**	**	v	***	***	v
	Fall 2014								
1 w	19.27 x	7.49C¶	13.08B	6.57	3.13	2.54B	3.70D	1.38C	9.59B
2	32.30	10.52C	36.24A	6.19	2.73	6.29A	6.83CD	2.10BC	27.16AB
3	44.00	11.71BC	39.31A	6.32	3.32	7.57A	10.22CB	4.17BC	44.88A
4	42.54	15.37AB	41.05A	5.74	2.76	7.20A	12.36B	4.78B	43.48A
5	43.25	18.76A	41.32A	6.69	2.76	6.93A	25.06A	9.94A	46.08A
p-value	NS	**	*	NS	NS	*	***	***	**

[y] 1 = no fertigation (bottom mix only); 2 = 168 kg N ha^{-1}, 25 kg P_2O_5 ha^{-1}, 140 kg K_2O ha^{-1}; 3 = 280 kg N ha^{-1}, 36 kg P_2O_5 ha^{-1}, 253 kg K_2O ha^{-1}; 4 = 393 kg N ha^{-1}, 48 kg P_2O_5 ha^{-1}, 365 kg K_2O ha^{-1}; and 5 = 505 kg N ha^{-1}, 59 kg P_2O_5 ha^{-1}, 477 kg K_2O ha^{-1}.
[x] Means in the same column and same season with different letters are significantly different using Duncan's multiple range test.
[w] 1 = no fertigation (bottom mix only); 2 = 112 kg N ha^{-1}, 20 kg P_2O_5 ha^{-1}, 84 kg K_2O ha^{-1}; 3 = 225 kg N ha^{-1}, 31 kg P_2O_5 ha^{-1}, 196 kg K_2O ha^{-1}; 4 = 337 kg N ha^{-1} ,42 kg P_2O_5 ha^{-1}, 309 kg K_2O ha^{-1}; 5 = 449 kg N ha^{-1} ,53 kg P_2O_5 ha^{-1}, 421 kg K_2O ha^{-1}.
[v] There were not fruit sample for that sampling.
NS = Nonsignificant at P < 0.05; *, **, ***Significant at P < 0.05, P <0.01 and P < 0.001, respectively

Table 3: Mean accumulation of nutrient (N, P and K) in the leaves, stems and fruit, 12 weeks after transplanting (WAT) in fall 2013, 11 WAT in spring 2014 and 13 WAT in fall 2014.

Fertilization rate	Total marketable yield	Total first harvest (sum of green and red large and extra-large categories)	Total final harvest (green and red large and extra-large)
	kg/ha		
	Fall 2013		
1[z]	23029C[y]	6725	17879C
2	36390B	10436	29999B
3	53723A	9668	44649A
4	60890A	9328	50374A
5	61271A	14841	48565A
p-value	***	NS	***
	Spring 2014		
1[x]	2804C	2344B	2344C
2	6563B	5559A	6251B
3	15477A	3237B	12672A
4	16348A	3717B	14377A
5	15107A	3072B	13537A
p-value	***	*	***
	Fall 2014		
1[x]	24461By	5083BC	14047B
2	42237A	7211AB	34259A
3	43137A	8925A	35581A
4	42145A	7757AB	32038A
5	39038A	2779C	29581A
p-value	*	NS	**

[z] Fertilization rate: 1 = no fertigation (bottom mix only); 2 = 168 kg N ha^{-1}, 25 kg P_2O_5 ha^{-1}, 140 kg K_2O ha^{-1}; 3 = 280 kg N ha^{-1}, 36 kg P_2O_5 ha^{-1}, 253 kg K_2O ha^{-1}; 4 = 393 kg N ha^{-1} , 48kg P_2O_5 ha^{-1}, 365 kg K_2O ha^{-1}; and 5 = 505 kg N ha^{-1}, 59 kg P_2O_5 ha^{-1}, 477 kg K_2O ha^{-1}.
[y] Means in the same column and same season with different letters are significantly different using Duncan's multiple range test.
[x] Fertilization rate: 1 = no fertigation (bottom mix only); 2 = 112 kg N ha^{-1}, 20 kg P_2O_5 ha^{-1}, 84 kg K_2O ha^{-1}; 3 = 225 kg N ha^{-1}, 31 kg P_2O_5 ha^{-1}, 196 kg K_2O ha^{-1}; 4 = 337 kg N ha^{-1} ,42 kg P_2O_5 ha^{-1}, 309 kg K_2O ha^{-1}; 5 = 449 kg N ha^{-1} ,53 kg P_2O_5 ha^{-1}, 421 kg K_2O ha^{-1}.
NS = Nonsignificant at $P < 0.05$; *, **, ***Significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 4: Total marketable yield at first harvest by fruit categories and total marketable yield in fall 2013, spring 2014 and fall 2014.

In the fall 2013 and fall 2014 seasons, there were no significant differences in total fruit (all marketable size categories combined) weight among fertilization rates at the first harvest (Figure 1 and Table 5). Total marketable yield and number of boxes per hectare for treatments 3, 4 and were higher than the average yield and number of boxes per hectare reported for fresh market in 2012. Whereas, the total marketable yields and number of boxes for treatments 1 and were lower than the state average.

There were significant differences among fertilization rates at first harvest (all size marketable categories combined) for only the spring 2014 season (Table 5). Total harvest yield for treatments 3, 4 and 5 were significantly greater than two lower fertilization rates. Thus, the fertilization rates that received more fertilizer than 393 kg ha^{-1} N and 365 kg ha^{-1} K in 2013 and 337 kg ha^{-1} N and 309 kg ha^{-1} K in 2014 were characterized as having excessive leaf and stem biomass compared with the treatment 3 rates, but had statistically the same yield in fruit per plant or area. Yield data collected during the fall 2013 and spring 2014 season indicated the 280 kg ha^{-1} N (2013) and 224 kg ha^{-1} N (2014) nitrogen rate produced significantly greater total yields than the lower nitrogen rates but not significantly different than the two higher nitrogen rates. Zotarelli et al. [11] and Scholberg et al. [2] found similar results indicating that applying more fertilizer than the recommended rate does not typically result in an increase in tomato yields. Santos [24] reported similar total marketable fruit yields among N rates ranging between 224 and 336 kg ha^{-1} irrigated with the seepage plus drip combination. However, there was a significant N effect in plots receiving only seepage irrigation with marketable fruit weight almost doubling from 12.0 to 22.7 tons/acre when applying 224 and 336 kg ha^{-1} N, respectively.

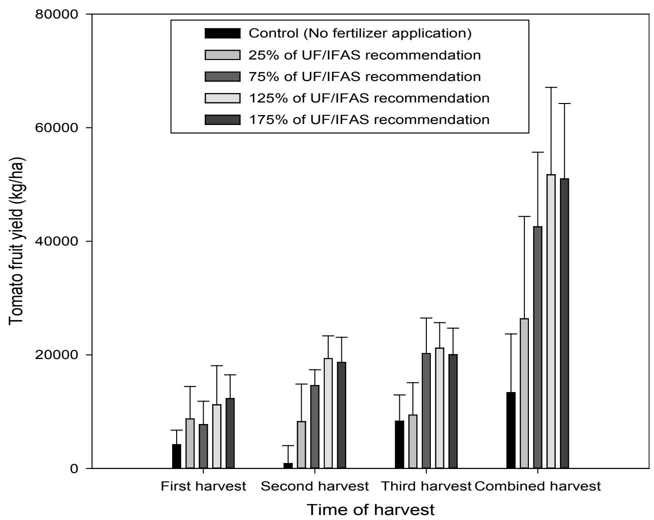

Figure 1: Tomato fruit yield in fall 2013 at first, second and third harvests in Immokalee, Florida.

Santos [25] demonstrated that K rates in the order of 336-560 kg ha^{-1} did not result in yield differences using seepage irrigation. This indicates that the irrigation system might have a bearing on potential nutrient uptake. Importantly, Zotarelli et al. [5] found that applying N in excess of the UF/IFAS recommendation on Florida sandy soil increased N leaching by 64, 59, and 32%, respectively, for pepper, tomato, and zucchini crops using drip irrigation. Likewise, other

Source	NH_4^+-N	NO_3^-–N	P	K
	Fall 2013			
Fertilization rate	***	***	NS	***
Position	NS	NS	NS	NS
Depth	*	**	***	NS
Sampling dates	***	NS	***	***
Fertilization rate*Depth	NS	NS	NS	NS
Sampling date*Fertilization rate	NS	*	NS	***
Sampling date*Fertilization rate*Depth	*	NS	NS	NS
	Spring 2014			
Fertilization rate	NS	*	NS	*
Position	NS	***	NS	NS
Depth	***	NS	NS	NS
Sampling date	***	NS	**	NS
Fertilization rate *Depth	NS	NS	NS	NS
Sampling date * Fertilization rate	*	***	NS	NS
Sampling date * Fertilization rate * Depth	NS	NS	NS	NS
	Fall 2014			
Fertilization rate	***	***	***	***
Position	NS	NS	NS	NS
Depth	NS	NS	***	***
Sampling date	***	***	***	***
Fertilization rate * Depth	NS	NS	NS	NS
Sampling date * Fertilization rate	***	***	**	***
Sampling date * Fertilization rate * Depth	NS	NS	NS	NS

NS = Nonsignificant at P < 0.05; *, **, *** Significant at P < 0.05, P < 0.01 and P <0.001, respectively.

Table 5: Analysis of variance (ANOVA) for NH_4^+-N, NO_3^-–N, P and K concentration in the soil in fall 2013, spring 2014 and fall 2014.

WAT	Fertilization rate[z]						Depth			
	NH_4^+-N (mg kg^{-1})									
	1	2	3	4	5	p-value	0-15 cm	15-30 cm	30-45 cm	p-value
0	10.44[x]	17.27	14.22	12.51	15.17	NS	12.35B[y]	18.29A	11.71B	**
4	1.24B	2.30B	2.15B	6.67A	5.22A	***	3.24	4.06	3.17	NS
9	0.37C	1.66C	3.03BC	5.79BA	7.40A	***	3.74	4.09	2.65	NS
13	0.72C	0.87C	1.49BC	4.06BA	5.44A	**	4.00	1.90	1.64	NS

[z] Fertilization rates: 1 = no fertigation (bottom mix only); 2 = 168 kg N ha^{-1}, 25 kg P_2O_5 ha^{-1}, 140 kg K_2O ha^{-1}; 3 = 280 kg N ha^{-1}, 36 kg P_2O_5 ha^{-1}, 253 kg K_2O ha^{-1}; 4 = 393 kg N ha^{-1} , 48kg P_2O_5 ha^{-1}, 365 kg K_2O ha^{-1}; and 5 = 505 kg N ha^{-1}, 59 kg P_2O_5 ha^{-1}, 477 kg K_2O ha^{-1}.

[y] Means in the same row with different letters are significantly different using Duncan's multiple range test.

NS=Nonsignificant at P<0.05; **, ***Significant at P<0.01 and P<0.001, respectively.

Table 6: Interaction of fertilization rate by weeks after transplanting (WAT) and depth for means of soil NH_4^+-N in fall 2013.

researchers in Florida found that an application greater than 168 kg ha^{-1} of N in drip irrigated tomatoes did not result in greater yield [11,26], agreeing with the yield results for this study for N rates > 224 kg ha^{-1}.

Soil nutrient distribution in the soil

Soil samples were collected at the experimental site four times during each season (once each month) in order to determine the nutrients status in the soil. Interaction of sampling dates by fertilization rate and soil depth was significant for NH_4^+-N for the fall 2013 season (Table 6). Soil NH^+ concentration increased with fertilizer N rate with significantly greater concentrations for treatments 4 and 5 and at the 15-30 cm depth (Table 7). Significant differences for sampling dates were found for P (Table 6), where the lowest concentration of P was observed at 9 weeks after transplanting (WAT) and highest at 4 WAT, but 0, 4 and 13 WAT were similar in P concentrations (Tables 8-10). Season-long mean NO_3-N and P had significant differences among depths (Table 6). The soil concentration of NO_3^--N increased with fertilizer rates for all sampledates whereas soil K concentrations was greatest at 4 and 9 WAT for the treatment 2 rate (Table 8). Soil NH_4^+ was greater in the top 15 cm than in the 15-30 and 30-45 cm soil depth for all threeseasons, while P concentration were greatest in the 15-30 cm depth and the lowest at 30-45 cm soil depth for the fall 2013 and fall 2014 seasons (Table 9), Season-long mean K and P had significant differences among depths. The highest concentration of K was in the top 0-15 cm mean while there were not significant differences between the depths 15-30 and 30-45 cm (these depths presented the lowest concentrations), for P the highest concentration was observed at 0-15 and 15-30 cm (there were not significant differences between these depths) and the lowest concentration was at 30-45 cm. These data indicate that applications of fertilizer through fertigation help to keep the nutrients in the root zone and can lead to improve the uptake of nutrientsthrough the roots system of the tomatoes. In fall 2013 season, the lowest concentration of NO_3-N were observed at 15-30 and 30-45 cm. Hebbar et al. [19] found similar results where the lowest concentration of NO_3-N was observed at the 30-45 cm in the treatment of normal fertilizer fertigation. Also, NH_4^+-N highest concentration was in the top 0-15 cm in the spring 2014 season. On the other hand, the highest concentration of NO_3-N was found in the top 0-15 cm for

	Nutrient concentration, mg kg^{-1}							
	sampling WAT							
Fertilization rate[z]	NO_3^-–N				K			
	0	4	9	13	0	4	9	13
	Fall 2013							
1	3B‡	0.50C	0.16C	0.40B	28A	17B	46B	21AB
2	3B	1BC	3BC	1B	31A	90A	281A	7B
3	2B	2BC	5B	3B	44A	52AB	26B	21AB
4	5A	8A	6B	8A	37A	18B	35B	28A
5	6A	4B	12A	8A	36A	27B	51B	35A
p-value	***	***	***	***	NS	*	***	NS
	NO_3^-–N				NH_4^+-N			
	0	4	8	11	0	4	8	11
	Spring 2014							
1[y]	6.40[x]	2.34	7.43	0.56D[x]	21.51	6.41	3.93	1.31C
2	5.75	7.25	5.63	1.88DC	20.08	5.33	2.01	1.85C
3	5.37	5.94	5.04	6.53BA	20.31	6.52	1.23	5.29B
4	4.35	4.56	11.73	5.05BC	17.89	8.53	5.86	2.13C
5	5.61	5.83	6.13	9.70A	21.73	4.50	4.70	9.28A
p-value	NS	NS	NS	***	NS	NS	NS	***
	K				P			
	0	4	8	13	0	4	8	13
	Fall 2014							
1[y]	23.84A[x]	17.62C	15.92B	6.75C	146.26B	168.58AB	168.29B	169.77A
2	15.03B	21.84BC	13.89B	9.83BC	124.18C	156.42B	162.32B	162.50A
3	10.64C	25.99B	16.27B	9.48BC	143.94B	185.43A	207.41A	178.42A
4	15.63B	23.94B	14.95B	12.63B	145.69B	151.39B	163.94B	140.50B
5	20.99A	34.65A	26.37A	28.16A	169.64A	186.87A	207.56A	178.23A
p-value	***	***	*	***	***	**	***	**
	NH_4^+-N				NO_3^-–N			
	0	4	8	13	0	4	8	13
1	35.63A	6.26B	5.15B	0.87	6.98A	6.65C	6.59B	0.67B
2	20.88B	4.80BC	4.54B	2.95	3.09BC	7.89C	8.02B	3.11B
3	18.12B	3.82BC	5.07B	1.09	1.72C	9.65BC	10.72B	1.23B
4	27.22AB	1.82C	2.90B	1.87	1.99C	14.08B	12.10B	4.35B
5	39.12A	10.66A	9.53A	2.68	4.24B	25.51A	29.38A	22.09A
p-value	**	***	***	NS	***	***	***	***

[z] Fertilization rates: 1 = no fertigation (bottom mix only); 2 = 168 kg N ha^{-1}, 25 kg P_2O_5 ha^{-1}, 140 kg K_2O ha^{-1}; 3 = 280 kg N ha^{-1}, 36 kg P_2O_5 ha^{-1}, 253 kg K_2O ha^{-1}; 4 = 393 kg N ha^{-1} , 48kg P_2O_5 ha^{-1}, 365 kg K_2O ha^{-1}; and 5 = 505 kg N ha^{-1}, 59 kg P_2O_5 ha^{-1}, 477 kg K_2O ha^{-1}.

[y] Fertilization rates: 1 = no fertigation (bottom mix only); 2 = 112 kg N ha^{-1}, 20 kg P_2O_5 ha^{-1}, 84 kg K_2O ha^{-1}; 3 = 225 kg N ha^{-1}, 31 kg P_2O_5 ha^{-1}, 196 kg K_2O ha^{-1}; 4 = 337 kg N ha^{-1} ,42 kg P_2O_5 ha^{-1}, 309 kg K_2O ha^{-1}; 5 = 449 kg N ha^{-1} ,53 kg P_2O_5 ha^{-1}, 421 kg K_2O ha^{-1}.

[x] Means in the same column and same season with different letters are significantly different using Duncan's multiple range test.

NS = Nonsignificant at $P < 0.05$; *, **, ***Significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 7: Means of fertilizations rates with weeks after transplanting (WAT) of concentration of NO_3^-–N and K in fall 2013, NH_4^+-N, NO_3^-–N in spring 2014 and NH_4^+-N, NO_3^-–N, K and P in fall 2014 in the soil.

the present study, which shows how the use of fertigation helps to keep the NO_3-N in the root zone areareducing the risk of leaching. Similar observations were found by Kadyampakeni et al. [27,28] in a study on citrus trees.

In the fall 2013 season the greatest concentration of P was found at 15-30 cm similar results were found in the fall 2014 season were the highest concentration of P in the soil was found at 0-15 and 15-30 cm. In the same season, the highest concentration of K was found in the top 0-15 cm and the lowest at the 15-30 and 30-45-cm soil depth. Soil P concentrations were significantly lower at 9 WAT for both fall 2013 and spring 2014, potentially indicating reduced availability at suggest application timings (Table 10). Soil K concentrations were significantly greater for treatments 3, 4 and 5. In fall 2013 season the lowest concentration of P was at 9 WAT and highest at 4 WAT but 0, 4 and 13 WAT were similar in P concentrations, meanwhile at spring 2014 season the highest concentration of NH_4-N at 11 WAT was found using 200% of UF/IFAS recommendation.

Conclusions

The tomato plants that received more fertilizer than 280 kg ha^{-1} N and 253 kg ha^{-1} K (2013) or 224 kg ha^{-1} N and 196 kg ha^{-1} K (2014) had excessive leaf and stem biomass compared with lower N and K rates, but had statistically no increase in fruit yield per plant or area. Fruit yield of the same N and K rates (treatment 3) was not significantly different than the two higher N and K rates. The lack of yield increase shows that even though plants received more fertilizer, these fertilization rates did not produce significantly more fruit than moderate N and K rates. These results confirm the hypothesis that applying more fertilizer than

Depth (cm)	Nutrient concentration (mg kg^{-1})	
	Fall 2013	
	NO_3^-N	P
0-15	5.07A[z]	162.68B
15-30	3.72B	175.02A
30-45	2.86B	152.47C
p-value	**	***
	Spring 2014	
	NH_4^+-N	
0-15	11.10A	NA[y]
15-30	7.75B	NA
30-45	6.80B	NA
p-value	***	NA
	Fall 2014	
	K	P
0-15	20.84A	168.55A
15-30	16.65B	169.34A
30-45	16.56B	157.08B
p-value	***	***

[z] Means in the same column and same season with different letters are significantly different using Duncan's multiple range test.
[y] Not applicable.
**, ***Significant at $P < 0.01$ and $P < 0.001$, respectively.

Table 8: Mean NO_3^-N and P concentration in fall 2013, NH_4^+-N concentration in spring 2014, K and P concentration in fall 2014 at 0-15, 15-30 and 30-45-cm soil depth.

Fall 2013	P	Spring 2014	P
WAT	mg kg^{-1}	WAT	mg kg^{-1}
0	169.12A[z]	0	110.32A[z]
4	171.74A	4	107.65BA
9	149.37B	8	104.18B
13	162.68A	11	107.35BA
p-value	***		*

[z] Means in the same column with different letters are significantly different using Duncan's multiple range test.
*, ***Significant at $P < 0.05$ and $P < 0.001$, respectively.

Table 9: Mean soil phosphorus concentration at different weeks after transplanting (WAT) in fall 2013 and spring 2014.

Fertilization rate[z]	K mg kg^{-1}
1	16.448B[x]
2	16.078B
3	28.873BA
4	22.749BA
5	40.617A
p-value	*

[z] Fertilization rate: 1 =no fertigation (bottom mix only); 2 =112 kg N ha^{-1}, 20 kg P_2O_5 ha^{-1}, 84 kg K_2O ha^{-1}; 3 =225 kg N ha^{-1},31 kg P_2O_5 ha^{-1},196 kg K_2O ha^{-1}; 4 =337 kg N ha^{-1} ,42 kg P_2O_5 ha^{-1}, 309 kg K_2O ha^{-1}; 5 =449 kg N ha^{-1} ,53 kg P_2O_5 ha^{-1}, 421 kg K_2Oha^{-1}.
[x] Means in the same column with different letters are significantly different using Duncan's multiple range test.
*Significant at $P<0.05$.

Table 10: Mean potassium concentration in the soil among fertilization rates in spring 2014.

recommended does not result in greater yields. Thus, the application of more fertilizer for tomato grown on sandy soils of Florida under drip fertigation does not typically result in a significant increase in yields. Soil nitrate concentrations highest soil concentration in top 0-15 cm at 7 cm distance from the fertigation line in fall 2013 and in the spring 2014. Highest phosphorus concentration was found in the 0-30 cm soil depth in both fall seasons. The highest K concentrations were found in the top 0-15 cm in the fall season 2014. This study showed how the implementation of drip irrigation system helps to maintain the nutrients in the root zone for enhanced uptake as a function of soil depth and drip per placement.

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