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Effect of Controlled-release and Soluble Fertilizer on Tomato Grown with Seepage Irrigation in Florida Sandy Soils

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Florida best management practices include the use of controlled-release fertilizers (CRFs), which are soluble nutrients coated with a resin, polymer, sulfur, or a hybrid of sulfur and polymer. The purpose of this study was to evaluate the effects of three CRF rates in a hybrid CRF/soluble nitrogen fertilizer (SNF) system and two SNF rates using seepage irrigation on tomato (*Solanum lycopersicum* L.) yields, petiole sap nitrate (NO_3-N) content, and postharvest fruit quality. Treatments of 100, 150, and 200 lb/acre CRF plus 50 lb/acre of SNF for total N of 150 (CRF100/SNF50), 200, and 250 lb/acre were compared with IFAS (230 lb/acre) and grower (250 lb/acre) standard of SNF applied pre-plant. Tomatoes were planted on 29 Aug. 2011 using polyethylene mulch. Petiole sap NO_3-N contents were above the IFAS sufficiency range for all treatments and sample dates. Soil temperatures ranged from 59.4 to 104.2 °F and averaged 79.1 °F during the trial, which is higher than the temperature at which manufacturers demonstrate N release. There were no differences in extra-large and total marketable yield at first harvest and total extra-large yield (three harvests combined) among treatments. However, total marketable yield for IFAS, CRF100/SNF50, 150/SNF50, and 200/SNF50 was greater than the grower standard, which ranged from 1,830 to 2,175 25-lb boxes/acre. Grower standards had greater firmness (less fruit deformation) than CRF200/SNF50 13 days after harvest (DAH). Treatments CRF100/SNF50 and 200/SNF50 had the greatest red color among the treatments 13 DAH. A hybrid system containing a significant portion of CRF plus SNF will allow reduced N application with yields similar to IFAS recommended rates.

Florida ranks first in the USA for fresh-market tomato (*Solanum lycopersicum* L.) with 31,000 acres harvested at a value of $564 million (U.S. Department of Agriculture, 2012). The Federal Environmental Protection Agency (EPA) and Florida Department of Environmental Protection (FDEP) have recognized the importance of water quality through the implementation of the Federal Clean Water Act of 1972 and the Florida Restoration Act of 1999 (Bartnick et al., 2005). To improve water quality, the Florida Department of Agriculture and Consumer Services (FDACS) adopted the Florida Vegetable and Agronomic Crops Best Management Practices (BMPs) manual (www.floridaagwaterpolicy.com). Polyethylene mulch, split soluble fertilizer (SF) applications, fertigation, and enhanced efficiency fertilizers (EEF) are recognized as nutrient management BMPs. Polyethylene mulch protects fertilizer from leaching due to rainfall; however, in seepage irrigation, rainfall may induce fertilizer leaching by causing water table fluctuation (Hochmuth et al., 2012). Fertigation is limited to drip irrigated production systems and split SF applications are used only after hurricanes or heavy rainfall events when tissue N or petiole sap NO_3-N content test below adequate, due to high labor cost (Cantliffe et al., 2006). Enhanced efficient fertilizers reduce the risk of nutrient loss to the environment and subsequently increase N use efficiency (NUE). There are three subgroups of EEF: slow-release fertilizers (SRF), controlled-release fertilizers (CRFs) and stabilized fertilizers (Slater, 2010). This paper will focus on CRFs, which are SFs such as urea, ammonium nitrate (NH_4NO_3), or potassium nitrate (KNO_3) coated with a polymer, resin, sulfur, or a hybrid of sulfur and a polymer (Trenkel, 2010). These coated fertilizers release nutrients into water at a predictable, temperature-dependent rate (Trenkel, 2010).

In tomato production systems using seepage irrigation, fertilizer may be placed at bed formation as a bottom ("cold mix") and a top ("hot mix") mix (Simonne and Hochmuth, 2010). The bottom mix is placed prior to false bedding, and the top mix for tomato production is placed in two bands on the shoulders of the bed (Simonne and Hochmuth, 2010). Seepage irrigation consists of managing a water table perched above a slowly permeable soil layer (hard pan) located at 30 to 60 inches below the surface. Pumped into canals or ditches, ground or surface water moves horizontally between adjacent ditches (spaced 75 to 100 ft). When water from adjacent ditches meets, the water table rises, thereby irrigating the crop from the hard pan to the soil surface (Ozores-Hampton et al., 2010).

When SRFs and CRFs were used as a singular N source in the bottom mix (resin coated urea, resin coated KNO_3, methylene urea, and polymer sulfur coated urea) or top mix [(methylene urea and polymer coated urea (PCU)] during a spring season, lower or similar extra-large and total marketable tomato yields were found as compared to SF. These results were due to lower ammonium and nitrate (NO_3^-) soil concentrations during the season or to slow N release from the SRF or CRF (Csizinszky, 1994; Ozores-Hampton et al., 2009). Ozores-Hampton et al. (2009) created a "hybrid fertilizer system" containing the majority of the N as CRF applied as a bottom mix, with the remainder of the N as SF in the top mix to increase soil soluble N concentration during the tomato growing season. Using the hybrid fertilizer system in a winter crop, Ozores-Hampton et al. (2009) found

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total marketable tomato yields similar to SF at equal and lower N rates with controlled-release KNO_3 fertilizer. Therefore, the objective of this study was to compare the effects of three CRF (coated, homogenized NH_4NO_3 and urea and coated KNO_3) rates in a hybrid fertilizer system and two SF programs (UF/IFAS and grower standard) on seepage irrigated fall tomato yields, petiole sap NO_3^- content, and postharvest fruit quality.

Material and Methods

A CRF fertilizer study was conducted in fall 2011 on a commercial tomato farm near Immokalee, FL (26°14'5" N/81°28'55" W) with cultivar BHN 726. The soil in the field was a Basinger fine sand (hyperthermic Spodic Psammaquents), which makes it possible to use seepage irrigation. Irrigation ditches were placed every six beds with a road in the center. The experimental design was a randomized complete-block design with four replications. A Florikcote (Florikan, Sarasota, FL) CRF mix composed of homogenized NH_4NO_3 and urea, coated (28N–0P–0K, mixture of 100- and 140-d release) and coated KNO_3 (12N–0P–40K, 180-d release) was applied at 100, 150, and 200 lb/acre CRF-N as a bottom mix plus 50 lb/acre soluble N fertilizer (SNF) as NH_4NO_3 in the top mix for total N of 150, 200, and 250 lb/acre. The IFAS and grower treatments were 169 and 219 lb/acre SNF, respectively, in the top mix as NH_4NO_3 and 21 lb/acre SNF as NH_4NO_3 and 10 lb/acre methylene urea in the bottom mix for a total of 200 and 250 lb/acre N. The IFAS treatment received 30 lb/acre N liquid fertilizer injected following a leaching rainfall event on 28 Oct. 2011 for a total of 230 lb/acre. All plots received 100 lb/acre P_2O_5 as triple super phosphate and 40 lb/acre K_2O as potassium-magnesium sulfate in the bottom mix. Additionally, the CRF treatments received 130 lbs/acre K_2O from the KNO_3 CRF in the bottom mix. The remainder of the K_2O, as sulfate of potash, 390 lb/acre and 260 lb/acre for the SF and CRF treatments, respectively, was applied in the top mix for a total of 430 lb/acre K_2O.

Tomatoes were grown following industry standards for production practices (Table 1) and UF/IFAS recommendation for pest and disease control (Olson et al., 2011). Fruit ranging from marketable mature green to ripe were harvested three times and graded in the field for extra-large, large, medium, and unmarketable fruit according to USDA standards (Agriculture Marketing Service, 1997). Plots were clearly marked to prevent unscheduled harvest by commercial crews.

Soil temperature data were collected using a Watchdog data logger (model B100; Spectrum Technologies Inc., Plainfield, IL) placed 4 inches deep in the bed. Monitoring wells were constructed from 40-inch-long, 4-inch-diameter PVC pipes screened at the bottom 12 inches (Smajstrla, 1997). A float was attached to one end of a 0.75-inch PVC pipe that was demarcated every inch to indicate the water table depth below the plastic mulch bed surface. Observations of the water table depth were taken throughout the growing season in four wells installed in the field (one in the center bed of each replication).

Beginning at first flower and until second harvest, six of the most recently fully-mature leaves were collected twice monthly during the crop cycle (a total of seven times), and nitrate (NO_3-N) content in fresh petiole (with leaflets attached) sap was measured using a Horiba Cardy Meter (Spectrum Technologies; Olson et al., 2011).

A subsample of 10 fruit at the mature green stage was collected, the fruit washed with chlorinated water, dried, and transported to the Gargiulo packing-house in Immokalee, FL to ripen with 13 d of ethylene treatment at 68 °F with 85% to 90% relative humidity (Sargent et al., 2005). Then, ripe tomatoes were transported to the UF/IFAS Vegetable Horticulture Laboratory in Immokalee, FL, rated for color using a 1-to-10 scale (1 = green;10 = purple), and firmness was measured as fruit deformation by a texture analyzer (Model C125EB; Mitutoyo Corp., Aurora, IL).

Yield data, petiole sap NO_3-N content, and postharvest measurements were analyzed using analysis of variance and means were separated using Duncan's Multiple Range Test, 5%, level (SAS version 9.3, SAS Institute Inc, Cary, NC, 2011). Orthogonal linear contrast was used to compare the yield and firmness among CRF treatments.

Table 1. Summary of cultural practices and research methods used in testing the effects of five controlled-release fertilizer/soluble nitrogen fertilizer rates on tomato grown with seepage irrigation in Southwest Florida.

Source	Cultural practice
Variety	BHN 726
Plant spacing (inches)	20
Bed spacing (ft)	6
Bed width (inches)	30
Fumigant	Methyl bromide/chloropicrin (50:50), 75 lb/acre
Mulch	White virtually impermeable film,1.5 mil
Planted plot length (ft)	30
Harvest plot length (ft)	16.7
Replications	4
Bedding date	2 Aug. 2011
Transplant date	29 Aug. 2011
Harvest dates	14 Nov. 2011, 1 Dec. 2011, and 15 Dec. 2011

Results and Discussion

Weather conditions. Overall, weather was normal, hot and humid throughout the fall season (Table 2). The minimum and maximum air temperatures were 43.6 and 100.9 °F. Rainfall totaled 18.3 inches with one leaching rain event on 28 Oct. 2011; therefore, 30 lb/acre soluble N fertilizer was added to the IFAS treatment. Cantliffe et al. (2006) define a leaching rain event as 3 inches of rainfall in 3 d or 4 inches in 7 d. Soil temperature at 4 inches below the bed surface averaged between 68.4 and 88.1 °F, with several days reaching over 100 °F (Table 3). Manufacturers of CRF measure nutrient release usually at a constant 75

Table 2. Summary of temperature and total rainfall in Immokalee, FL during fall 2011.

	Air temp (°F)			Total rainfall
Period	Avg	Min	Max	(inches)
Aug.	80.9	71.4	100.9	5.2
Sept.	80.3	65.1	99.3	4.0
Oct.	73.4	50.4	92.3	8.4
Nov.	69.3	47.4	92.7	0.1
Dec.	66.7	43.6	84.5	0.6
Avg/Total	74.1	53.3	93.9	18.3

Table 3. Summary of maximum, minimum, and average soil temperature (°F) at 4 inches below the bed surface and air temperature in Immokalee, FL during fall 2011.

	Soil temp (°F)			Air temp
Date measured	Max	Min	Avg	(°F)
9 Aug. 2011	104.2	78.3	86.2	81.7
16 Aug. 2011	103.3	77.4	86.7	81.3
23 Aug. 2011	103.3	77.4	86.5	80.4
30 Aug. 2011	99.7	77.4	85.4	80.7
6 Sept. 2011	98.1	76.5	83.9	79.6
13 Sept. 2011	103.3	77.4	88.1	81.4
20 Sept. 2011	101.5	78.3	87.3	80.5
27 Sept. 2011	98.1	75.6	83.7	79.4
4 Oct. 2011	98.1	72.9	84.0	77.5
11 Oct. 2011	92.7	72.0	80.0	75.6
18 Oct. 2011	92.7	74.7	79.2	75.7
25 Oct. 2011	85.5	64.8	73.9	68.1
1 Nov. 2011	83.7	68.4	75.5	72.5
8 Nov. 2011	82.8	63.9	72.5	68.2
15 Nov. 2011	81.0	62.1	71.3	68.0
22 Nov. 2011	85.5	70.2	76.0	74.0
29 Nov. 2011	82.8	66.6	72.8	68.0
6 Dec. 2011	78.3	59.4	68.4	64.3
13 Dec. 2011	80.1	63.9	70.8	68.1
20 Dec. 2011	79.2	61.2	69.8	66.5
Avg/Total	91.7	70.9	79.1	74.6

°F. Thus, the high bed temperatures may accelerate the N release rate of CRFs and shorten the release duration (Engelsjord et al., 1996; Huett and Gogel, 2000). Therefore, an appropriate CRF N release duration will need to be determined for fall, winter, and spring season that will match tomato crop temporal N uptake.

Water table depth. Water table depths fluctuated between 25 and 17 inches below the bed surface during the crop cycle (Fig. 1). The water table depths were recorded seven times throughout the season and indicated minimal movement; however, with intervals of 2 weeks or greater between water table observations, there may have been water table fluctuations due to rainfall or management that were not detected.

Plant nutritional status response to CRF N rates. There were no differences among treatments for petiole sap NO_3-N content at any sampling dates. Also, petiole sap NO_3-N content for all treatments and sample dates were above the UF/IFAS upper sufficiency range (Olson et al., 2011). Thus, according to UF/IFAS recommended petiole sap NO_3-N guidelines, N was not a limiting factor during the crop cycle (Fig. 2). Overall, petiole sap NO_3-N content decreased from first bud to second harvest, following a typical pattern observed in seepage irrigated tomatoes (Ozores-Hampton et al., 2007). Uncharacteristically low NO_3-N petiole sap contents (for this trial) were measured at 63 d after transplant, which was probably due to the only leaching rain event of the season (Table 2).

Yield responses to CRF N rates. There were differences ($P \leq 0.05$) among treatments in medium fruit and total (all sizes combined) marketable tomato yield for the first and second combined harvest, season medium fruit, season total marketable tomato yield (all sizes and three harvests combined), and total (three harvests combined) unmarketable yield (Table 4). IFAS, CRF100/SNF50, and CRF150/SNF50 treatments had the greatest and growers the lowest medium tomato yield for the first and second combined harvest. For total marketable yield of first and

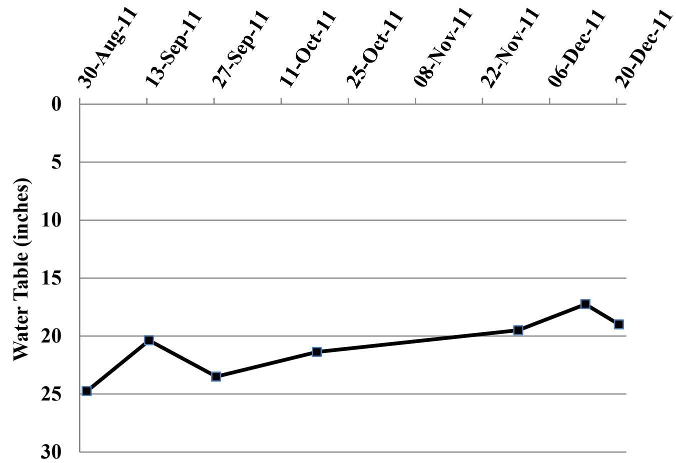

Fig. 1. Water table levels for tomato grown with seepage irrigation in Immokalee, FL during fall 2011.

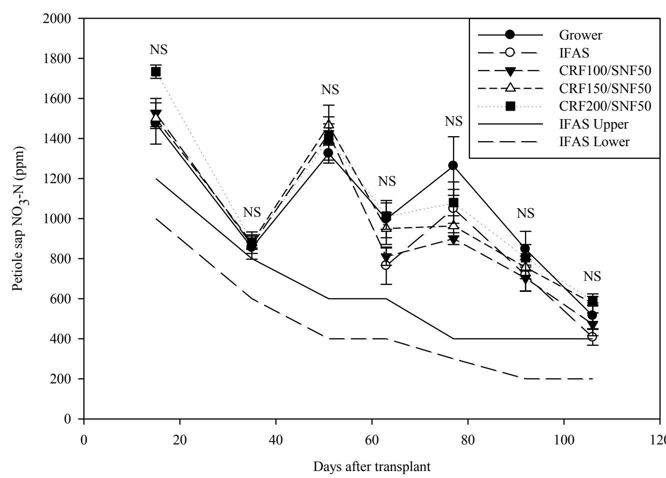

Fig. 2. Changes of petiole sap nitrate concentration (ppm) for tomatoes grown with five different controlled-release fertilizer (CRF)/soluble nitrogen fertilizer (SNF) programs in Immokalee, FL during fall 2011.

second combined harvest, CRF100/SNF50 and CRF150/SNF50 had the greatest tomato yields, although CRF150/SNF50 was not different from CRF200/SNF50 or IFAS, and both were not different from the grower treatment. The IFAS treatment had a greater season medium tomato yield than all other treatments. For season total harvest, all CRF and IFAS treatments were greater than the grower treatment. The grower, CRF100/SNF50, and CRF150/SNF50 treatments had fewer unmarketable fruit than the IFAS and CRF200/SNF50 treatments. There were no differences for any tomato size or total marketable yield category in the first harvest, or extra-large and large size categories in the first and second combined harvests and season total marketable harvests. When linear contrasts were performed among CRF treatments, there was no response to N rate [Table 4 ($P \leq 0.05$)]. Similarly, using a "hybrid CRF/SF fertilizer system" in a spring season with seepage irrigation, Ozores-Hampton et al. (2009) found no differences in marketable first harvest yields in tomatoes grown with three rates of KNO_3 CRF plus 100 lb/acre SNF, but for season total

Table 4. Fruit yield by size categories for first harvest, first and second harvest combined, and season total harvest (three harvests combined) for five controlled-release fertilizer (CRF)/soluble nitrogen fertilizer (SNF) programs in tomato grown in Immokalee, FL during fall 2011.

	First harvest				First and second harvests				Season total harvest				
Treatments	Xlg[z]	Lrg	Med	Total	Xlg	Lrg	Med	Total	Xlg	Lrg	Med	Total	Cull
	---------- *(25-lb boxes/acre)* ----------												
Grower	330	62	21	413	722	418	327 c[y]	1467 c	773	537	521 b	1830 b	350 b
IFAS[x]	368	63	13	445	592	471	467 a	1530 bc	627	586	881 a	2094 a	547 a
CRF100/SNF50	400	66	21	487	737	553	427 ab	1717 a	811	675	689 b	2175 a	375 b
CRF150	280	82	18	380	629	559	423 ab	1611 ab	689	697	665 b	2051 a	424 b
CRF200	306	77	23	406	658	539	391 b	1588 bc	701	675	675 b	2051 a	549 a
P value	0.07	0.79	0.70	0.18	0.21	0.15	0.001	0.006	0.11	0.12	0.0009	0.02	0.0002
Significance	NS	NS	NS	NS	NS	NS	**	**	NS	NS	**	*	**
Contrast linear (CRF only)	0.58	0.82	0.55	0.63	0.65	0.74	0.40	0.73	0.85	0.71	0.88	0.99	0.12
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Xlg = 5×6 or extra large; Lrg = 6×6 or large; Med = 6×7 or medium.
[y]Within columns, means followed by different letters are significantly different according to Duncan's Multiple Range Test, 5% level.
[x]Total N rate includes 200 lb/acre N in the top mix and 30 lb/acre liquid fertilizer applied following a leaching rain event on 28 Oct. 2011.
NS, *, **Nonsignificant or significant at $P \leq 0.05$ or ≤ 0.01, respectively.

Table 5. Postharvest firmness and color after a 13-d ripening with ethylene gas for tomatoes grown using five different controlled-release fertilizer (CRF) and soluble nitrogen fertilizer (SNF) programs in Immokalee, FL during fall 2011.

Treatment	Firmness deformation (mm)[z]	Color rating 1–10)[y]
Grower	2.57 c[x]	5.0 c
IFAS	2.96 bc	5.5 b
CRF100/SNF50	2.64 c	6.0 a
CRF150	3.19 ab	5.0 c
CRF200	3.39 a	6.0 a
P value	0.0002	0.0001
Significance	**	**
Contrast linear (CRF only)	0.17	---
Significance	NS	---

[z]Very firm ≤ 0.7 mm; firm ≤ 1.4 mm; medium ≤ 2.1 mm; soft ≤ 2.8 mm; very soft ≥ 3.9 mm.
[y]5 = light red; 6 = red; and 7 = very red.
[x]Within columns, means followed by different letters are significantly different according to Duncan's Multiple Range Test, 5% level.
NS, *, **Nonsignificant or significant at $P \leq 0.05$ or ≤ 0.01, respectively.

harvest, the IFAS SF and CRF100/SNF100 treatments performed better than the CRF150/SNF100 treatment. In this study, IFAS SF and all CRF treatments produced higher marketable yields than the grower standard treatment. In a rate study using different portions of PCU, Csizinszky et al. (1993) found no difference in first harvest extra-large fruit yield or season total marketable yield. However, PCU use generally caused total marketable first harvest yield to decrease as the portion of total N made up by PCU increased, causing yield differences.

Postharvest quality. The firmest fruit (i.e., those with the least deformation) were from the grower, IFAS, and CRF100/SNF50 treatments, and the softest fruit were from CRF200/SNF50 (Table 5). However, there were no differences between IFAS and CRF150/SNF50 treatments. When linear contrasts were performed among CRF treatments, there was no response to N rate [Table 5 ($P \leq 0.05$)]. These differences may be attributed to the urea content in the CRF. However, there were no differences in tomato firmness in a spring trial using six CRF treatments containing resin coated urea and potassium nitrate, methylene urea, and polymer sulfur coated urea at two rates (Csizinszky, 1994). The highest color rating was for the CRF200/SNF50 and CRF100/SNF50 treatments and the lowest color rating was for the CRF150/SNF50 and grower treatments (Table 5). Thus, tomato color was not related to N sources and rate, but was probably related to the maturity of the tomatoes selected to be measured (Maul, 1999).

The high bed temperatures in this study compared to the temperature at which CRF manufacturers measure N release may have accelerated the N release rate of coated fertilizers and shorten the release duration. However, a CRF/SNF hybrid fertility program produced greater marketable tomato yields at 150 lb/acre total N than 250 lb/acre soluble N and equal yields compared to IFAS split application treatment with 230 lb/acre soluble N. The CRF200/SNF50 rate produced softer tomatoes at table ripeness than CRF100/SNF50 and the SF treatments

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