Effect of Controlled-release and Soluble Fertilizer on Tomato Production and Postharvest Quality in Seepage Irrigation

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Additional index words. BMP, enhanced efficiency, slow-release, soil nitrogen, *Solanum lycopersicum*, tissue analysis

Abstract. Florida best management practices include the use of controlled-release fertilizers (CRFs), which are soluble nutrients coated with a resin, polymer, sulfur, or a polymer covering a sulfur-coated urea. The purpose of this study was to compare the effects of three CRFs (coated, homogenized NH_4NO_3 and urea, and coated KNO_3) rates in a hybrid CRF/soluble nitrogen fertilizer (SNF) system and two SNF rates [University of Florida/Institute of Food and Agricultural Science (UF/IFAS) and grower standard] on seepage-irrigated fall tomato (*Solanum lycopersicum* L.) yields, leaf-tissue nitrogen (LTN) concentration, postseason soil nitrogen (N) content, and postharvest fruit quality. Treatments of 112, 168, and 224 $\text{kg}\cdot\text{ha}^{-1}$ CRF N plus 56 $\text{kg}\cdot\text{ha}^{-1}$ SNF for total N of 168 (CRF112/SNF56), 224, and 280 $\text{kg}\cdot\text{ha}^{-1}$ were compared with IFAS (224 $\text{kg}\cdot\text{ha}^{-1}$) and grower standard (280 $\text{kg}\cdot\text{ha}^{-1}$) of pre-plant SNF. Tomatoes were planted on 29 Aug. 2011 and 3 Sept. 2012 on polyethylene mulch. Air temperature averaged 23.0 and 22.6 °C for the 2011 and 2012 fall seasons with 33.4 and 37.4 cm of rainfall, respectively. Soil temperatures ranged from 15.2 to 40.1 °C in 2011 and 13.6 to 36.6 °C in 2012. Leaf tissue N concentration exceeded the UF/IFAS-recommended sufficiency range for all treatments and sample dates, except CRF112/SNF56 at the last sample date of 2012. There were no differences in extra-large and total marketable yield at first harvest nor in total extra-large yield (three harvests combined) among treatments in 2011; however, total marketable yield for UF/IFAS, CRF112/SNF56, 168/SNF56, and 224/SNF56 was greater than that of the grower standard. In 2012, CRF112/SNF56 and CRF168/SNF56 had the greatest first harvest extra-large and total yield, but there were no differences between season total marketable yields. No differences between treatments were found for total N remaining in the soil postseason in 2011 or 2012. The grower standard, UF/IFAS, and CRF112/SNF56 were firmer at red ripe (less fruit deformation) in 2011, but there were no differences in 2012. In 2011, CRF112/SNF56 and CRF224/SNF56 were rated highest in red color among the treatments, and in 2012 there were no differences. A hybrid system containing lower and equal N rates (112 to 168 $\text{kg}\cdot\text{ha}^{-1}$ CRF N and 56 $\text{kg}\cdot\text{ha}^{-1}$ SNF56) compared with UF/IFAS-recommended rates produced comparable marketable yield and fruit quality.

Florida ranks first in the United States for fresh-market tomato production value at \$267 million produced on 11,700 ha [U.S. Department of Agriculture (USDA), 2013]. The Federal Environmental Protection Agency and Florida Department of Environmental Protection recognize the importance of water quality through the enforcement of both the Federal Clean Water Act of 1972 and the Florida Restoration Act of 1999 (Bartnick et al., 2005). The Florida Vegetable and Agronomic Crops Best Management Practices

(BMPs) manual, adopted by the Florida Department of Agriculture and Consumer Services, contains a series of BMPs to maintain and ameliorate water quality (Bartnick et al., 2005).

The majority of the tomato production in southern Florida is seepage-irrigated, which involves managing a water table perched on a slowly permeable soil layer (argillic or spodic) located 0.6 to 0.9 m below the surface (Bonczek and McNeal, 1996). Ground or surface water pumped into a ditch that connects a series of parallel ditches spaced 20 to 30 m apart elevates a perched water table. Growers maintain the water table at 45 to 60 cm below the bed surface to irrigate the plants by capillarity (Bonczek and McNeal, 1996).

In seepage-irrigated tomato production, the UF/IFAS recommends application of all fertilizers at bed formation. Fertilizers may be applied as a “bottom mix” broadcast in-row before bed formation and as a “top mix” in bands on the bed shoulders after bed formation. The UF/IFAS-recommended bottom mix contains all phosphorus (P) and micro-nutrients and 10% to 20% of the N and potassium (K) (Liu et al., 2012). The remaining N and K are applied as a top mix. During the season, BMPs allow additional fertilizer application in the event of a leaching rainfall, low LTN or low petiole sap nitrate (NO_3^- -N) concentrations, or an extended harvest season. A leaching rain is defined as greater than 76 mm of rainfall in 3 d or greater than 102 mm in 7 d (Liu et al., 2012). The additional fertilizer may be applied by punching holes in the polyethylene mulch and hand-applying dry, granular fertilizer or by a liquid fertilizer injection wheel; however, both methods increase production costs (Liu et al., 2012).

The use of EEF, a Florida vegetable crop BMP, may reduce the risk of nutrient loss to the environment and can subsequently increase N use efficiency in seepage-irrigated tomato production (Carson and Ozores-Hampton, 2013; Trenkel, 2010). There are three subgroups of EEF: slow-release fertilizers (SRF), CRFs, and stabilized fertilizers (Slater, 2010). Slow-release fertilizers are long-chain molecules with reduced solubility, such as methylene urea, which typically need microbial degradation to release plant available N. Stabilized fertilizers are soluble ammonium (NH_4^+) or urea fertilizer applied with a nitrification inhibitor or urease inhibitor to maintain fertilizers in the original form as NH_4^+ or urea. Finally, CRFs are soluble fertilizers (SFs) such as urea, ammonium nitrate (NH_4NO_3), or potassium nitrate (KNO_3) coated with a polymer, resin, sulfur, or a polymer covering sulfur-coated urea (PSCU) (Trenkel, 2010). These coated fertilizers release nutrients into water at a predictable, temperature-dependent rate (Carson and Ozores-Hampton, 2013).

In sandy soils with seepage irrigation, when SRF and CRF were used as a singular N source in the bottom mix (resin coated urea, resin coated KNO_3 , methylene urea, and PSCU) or top mix (methylene urea and polymer-coated urea), lower or similar extra-large and total marketable tomato yields were found when compared with SF during a spring season (Csizinszky, 1989, 1992, 1994; Ozores-Hampton et al., 2009). The lower marketable yields were partially as a result of slow N release from the SRF or CRF and high NH_4^+ soil concentration caused by polymer-coated urea use (Csizinszky, 1994; Ozores-Hampton et al., 2009). Therefore, a “hybrid fertilizer system” was created to increase soluble N concentration in the soil during early tomato developmental stages (Ozores-Hampton et al., 2009). The hybrid fertilizer system consists of 50% to 75% of the N as CRF in the bottom mix with the remainder of the N as SF in the top mix. When the hybrid fertilizer system was used with CRF (KNO_3) at equal and lower

Received for publication 23 Sept. 2013. Accepted for publication 22 Nov. 2013.

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N rates, similar total marketable tomato yields were obtained compared with SF during a winter season eliminating the high NH_4^+ soil concentrations (Ozores-Hampton et al., 2009). Therefore, the objective of this study was to evaluate the effects of two SF rates and the hybrid fertilizer system with three CRF rates on tomato yields, LTN concentration, post-season soil N content, and postharvest fruit quality.

Materials and Methods

The hybrid fertilizer system studies were conducted on a commercial tomato farm near Immokalee, FL (lat. $26^{\circ}14'5''$ N, long. $81^{\circ}28'55''$ W) during Fall 2011 and Fall 2012 (Carson et al., 2012). The soil type was Basinger fine sand (hyperthermic Spodic Psammaquents), which permitted the use of seepage irrigation (Natural Resources Conservation Service, 2012). The field configuration from east to west consisted of an irrigation ditch, three beds, a drive road, three beds, and another irrigation ditch. The beds were 76 cm wide and 20 cm high with 1.8 m between bed centers. On 2 Aug. 2011 and 17 Aug. 2012, the beds were formed, fumigated with methyl bromide/chloropicrin (50:50 by weight) (ICL-IP, South Charleston, WV) at $84 \text{ kg}\cdot\text{ha}^{-1}$, fertilized, and covered with white virtually impermeable film (0.038 mm; Berry Plastic, Evansville, IN). A CRF mix (Florikan[®], Sarasota, FL) composed of coated, homogenized NH_4NO_3 and urea (28N-0P-0K, 100- and 140-d release) and coated KNO_3 (12N-0P-40K, 180-d release) (1.4:1:1.2, by weight) was applied at three N rates as a bottom mix (Table 1). Additional N as NH_4NO_3 was applied in the top mix to create treatments CRF112/SNF56, CRF168/SNF56, and CRF224/SNF56. The UF/IFAS and grower standard treatments contained NH_4NO_3 in the top mix and $24 \text{ kg}\cdot\text{ha}^{-1}$ N from NH_4NO_3 and $11 \text{ kg}\cdot\text{ha}^{-1}$ N from methylene urea in the bottom mix. After a leaching rainfall event on 28 Oct. 2011, the UF/IFAS treatment received $34 \text{ kg}\cdot\text{ha}^{-1}$ N as NH_4NO_3 fertilizer for a total of $258 \text{ kg}\cdot\text{ha}^{-1}$ N. No additional N was added during the 2012 season. In the bottom mix, P was applied as triple superphosphate and SF-K was applied as potassium magnesium sulfate. Potassium sulfate applied in the top mix provided the remainder of the K that was

not supplied in the bottom mix. On 29 Aug. 2011 and 3 Sept. 2012, tomato cultivar BHN 726 (BHNSeed Inc., Immokalee, FL) was planted in a single row with 51 cm between plants.

The experimental design was a randomized complete block design with four replications. The plots were 9.1 m long and three beds wide. The middle 5.1 m of the center row was harvested for collection of yield data.

The tomato crops were grown using industry standard production practices and UF/IFAS-recommended pest and disease control (Olson et al., 2012). A Watchdog data logger (Model B100; Spectrum Technologies Inc., Plainfield IL) collected soil temperature at 10 cm below the bed surface. The water table depth was recorded seven and 12 times during 2011 and 2012, respectively, from four monitoring wells (one in each replicate) installed in the trial, as described by Smajstrla and Muñoz-Carpena (2011).

Beginning at first flower (13 Sept. 2011 and 24 Sept. 2012), six most recently fully mature leaves were collected from each plot in ≈ 15 -d intervals for seven total collections. The leaf tissue was dried at 50°C and ground to pass through a 60-mesh sieve. Leaf tissue N concentration (%) was measured by combustion using a NA2500 C/N Analyzer (Thermo Quest-CE Instruments, Waltham, MA).

Before first harvest each year, all plots were covered with bird netting to prevent unscheduled harvest by commercial crews. Fruit ranging from marketable mature green to ripe were harvested three times (14 Nov., 1 Dec., and 15 Dec. 2011 and 11 Nov., 7 Dec., and 15 Dec. 2012) and graded in the field as extra-large (greater than 7.00 cm), large (6.35 to 7.06 cm), medium (5.72 to 6.43 cm), and unmarketable (cull) fruit according to USDA standards and weighed (USDA, 1997).

In 2011, a subsample of 10 mature green fruit was collected from each plot at first harvest, washed with chlorinated water (150 ppm), dried at room temperature, transported to a commercial packing facility in Immokalee, FL, and ripened with 150 ppm ethylene at 20°C and 85% to 90% relative humidity for 13 d (Sargent et al., 2005). Ripe tomatoes were transported to the UF/IFAS Southwest Florida Research and Education Center (SWFREC) Vegetable Laboratory in Immokalee, FL, where fruit firmness was measured

as fruit deformation using a texture analyzer (Model C125EB; Mitutoyo Corp., Aurora, IL) and fruit were rated for external color using the official USDA grade standards (1-to-6 scale, where 1 = green and 6 = red) (USDA, 1997). In 2012, to reduce variability resulting from maturity differences, the subsample size was increased to 20 mature green fruit, which were collected and ripened as described for 2011. However, the tomato fruit were removed from the ripening room at the first sign of breaker stage (3 d) and transported to the UF/IFAS SWFREC Vegetable Laboratory. Ten fruit from each plot, at the breaker stage of development, were selected and ripened at room temperature until full red ripe, which occurred 10 d after harvest. Fruit firmness and color were measured and rated as described for 2011.

Postseason soil samples were collected on 19 Dec. 2011 and 2 Jan. 2013 using a soil slicer (Muñoz-Arboleda et al., 2006). From the middle bed in the center of each plot, an 8.9-cm wide $\times$ 20-cm deep cross-section of the bed was sampled. The cross-section was divided into three vertical sections, homogenized, and subsampled. Soil samples were stored at less than 4°C until analysis. Before analysis, soil samples were sieved, weighed, and CRF prills were separated from the samples, weighed, crushed, and analyzed separately. Urea-N, NH_4^+ -N, and NO_3^- -N were extracted from a 4.5-g wet soil sample and CRF prills collected from the soil sample using 40 mL of 2 M KCl containing $14.8 \mu\text{mol}\cdot\text{L}^{-1}$ phenyl mercuric acetate (Mulvaney and Bremner, 1979; Sato and Morgan, 2008). Soil and CRF prill extracts were measured for NH_4^+ -N and NO_3^- -N by salicylate-hypochlorite, cadmium reduction using a Flow Analyzer (QuikChem 8500; Lachat Co., Loveland, CO) at 660 nm and 520 nm, respectively. Urea-N in the extracts was measured by modified diacetyl monoxime methods using a DR/4000U Spectrophotometer (Hach Co., Loveland, CO) at 527 nm (Sato et al., 2009; Sato and Morgan, 2008).

Yield data, LTN concentration, post-season soil N contents, and postharvest firmness and color 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). Linear contrast was used to compare

Table 1. Nutrient rates and bed placement used in testing controlled-release fertilizer (CRF) fall mixes in Immokalee, FL, during Fall 2011 and Fall 2012.

Treatment	Bottom mix ^z					Top mix				Total ^y					
	N		P	K		N		K		N			K		
	SF	CRF	SF	SF	CRF	SF	CRF	SF	CRF	SF	CRF	T	SF	CRF	T
	(kg·ha ⁻¹)														
Grower	24	11	49	37	0	245	0	363	0	269	11	280	400	0	400
IFAS ^x	24	11	49	37	0	189	0	363	0	213	11	224	400	0	400
CRF112/SNF56	0	112	53	33	124	56	0	243	0	56	112	168	276	124	400
CRF168/SNF56	0	168	53	33	124	56	0	243	0	56	168	224	276	124	400
CRF224/SNF56	0	224	53	33	124	56	0	243	0	56	224	280	276	124	400

^xN = nitrogen; P = phosphorus; K = potassium; SF = soluble fertilizer; T = total.

^yBottom mix P is the total P applied.

^zIn 2011, the Institute of Food and Agricultural Science treatment received an additional $34 \text{ kg}\cdot\text{ha}^{-1}$ N after a leaching rain event making the total N applied $258 \text{ kg}\cdot\text{ha}^{-1}$. No additional N was added during 2012.

the yield, postseason soil N contents, and postharvest measurements among CRF treatments. A Pearson's correlation coefficient was derived for soil and air temperatures.

Results and Discussion

Weather conditions. Overall, air temperatures during the 2011 and 2012 seasons were similar compared with the previous 10-year average fall temperature (August through December) [Florida Automated Weather Network (FAWN), 2013]. The minimum, average, and maximum air temperatures during the growing season (planting to third harvest) were 6.4, 23.0, and 37.4 °C in 2011 and 5.5, 22.6, and 34.2 °C in 2012, respectively. However, the cumulative fall rainfall was 2.5 cm lower and 10.2 cm higher during 2011 and 2012, respectively, than the 10-year average (FAWN, 2013). Total rainfall was 33.4 cm during the 2011 growing season with one leaching rain event (7.6 cm of rainfall in 3 d) on 28 Oct. 2011 after which 34 kg·ha⁻¹ SNF was added to the UF/IFAS treatment following UF/IFAS recommendations (Liu et al., 2012). During 2012, the total rainfall was 37.4 cm; however, there were no leaching rain events. Because the manufacturer of the CRF used in this study determined nutrient release at a constant 25 °C, air and soil temperatures differing from 25 °C will slow or accelerate nutrient release from CRFs (Engelsjord et al., 1996; Huett and Gogel, 2000). Thus, average weekly air temperatures greater than 25 °C from planting to 11 Oct. (2011) and 25 Oct. (2012) may have accelerated nutrient release from the CRFs as a result of increased soil temperature.

Soil temperatures. The mean season minimum, average, and maximum soil temperatures at 10 cm below the bed surface were 21.6, 26.2, and 33.2 °C during 2011 and 20.3, 24.7, and 31.1 °C during 2012, respectively; thus, soil temperatures averaged 1.5 °C higher in 2011 compared with 2012. When combining soil and air temperature data among 2011 and 2012, soil and air temperature were strongly correlated ($r = 0.95$; $P = 0.0001$). As such, air temperature can be a strong indicator of soil temperature. Thus, with higher air temperatures, the rate of release for CRF will increase over what was expected at 25 °C. Although no correlation coefficient was developed, Diaz-Perez and Batal (2002) found that the soil temperature under black, gray, and silver polyethylene mulch closely followed the air temperature pattern. Similarly, Zheng et al. (1993) reported that air temperature and soil temperature were highly correlated ($r = 0.85$ to 0.96) in bare soil and sod and that air temperature may be used as a soil temperature prediction tool. During Fall 2011, bed temperatures, which peaked at 40.6 °C and averaged between 19.7 and 30.3 °C, shortened CRF N release duration under white polyethylene mulch by 46% to 69% as compared with the manufacturer's expected nutrient release (Carson et al., 2013). Therefore, a season-specific CRF N release duration matching tomato crops temporal N uptake will be

required for fall, winter, and spring seasons as a result of season temperature differences.

Water table depth. Water table depths fluctuated between 0.43 and 0.63 m and 0.39 and 0.55 m below the bed surface during the 2011 and 2012 seasons, respectively. Water table depths were similar to those reported by Ozores-Hampton et al. (2012) for seepage-irrigated tomato in Immokalee, FL.

Plant nutritional status. There were interactions between year and treatment at several sample dates ($P \leq 0.05$); therefore, LTN data were presented by year (Fig. 1A–B). In 2011, CRF168/SNF56 had the greatest, whereas CRF112/SNF56 and CRF224/SNF56 had the lowest LTN concentration at 16 d after transplant (DAT) (Fig. 1A). At 78 and 107 DAT, the grower standard treatment had the greatest LTN concentration, whereas all other treatments were lower and similar. There were no statistical differences in LTN concentration from 36 to 64 and at 93 DAT. In 2012, at 67, 95, and 109 DAT, CRF112/SNF56 had the lowest LTN concentration but was not statistically different from CRF168/SNF56 at collections 67 and 109 DAT (Fig. 1B). The grower standard and CRF224/SNF56 treatments had the highest LTN concentrations at 67 DAT, but UF/IFAS was similar at 95 DAT, and UF/IFAS and CRF168/SNF56 were similar at 109 DAT. There were no statistical differences in LTN concentration from 22 to

Fig. 1. Leaf-tissue nitrogen (N) concentration for tomatoes grown with five controlled-release fertilizer (CRF)/soluble nitrogen fertilizer (SNF) programs in Immokalee, FL, during Fall 2011 (A) and Fall 2012 (B). NS, *, **, *** Nonsignificant or significance at $P \leq 0.05$, ≤ 0.01 , or ≤ 0.001 , respectively.

52 and at 82 DAT. During both years, all LTN values (except at 109 DAT in 2012) were higher than the upper sufficiency range for LTN.

Monitoring of LTN concentration allows growers to predict yield potential and to diagnose nutrient deficiencies before they might become visible on the plant, which allows for efficient fertilizer management (Hochmuth et al., 2010). According to UF/IFAS-recommended LTN guidelines, N was not a limiting factor for any N treatment during 2011 and 2012 because all but one sample was higher than the upper sufficiency range for LTN (Fig. 1). The yearly difference in LTN may be the result of the increased rainfall in Sept. 2012 compared with 2011. This increased rainfall in the early season may have resulted in nutrient leaching caused by water table fluctuations (Sato et al., 2009).

Yield responses to CRF N rates. There were interactions between year and N treatment; therefore, yield data were presented by year [$(P \leq 0.05)$ Table 2]. In 2011, there were differences ($P \leq 0.05$) among treatments in medium fruit and total marketable tomato (all marketable sizes combined) yield for the first and second combined harvest (FSHC), season medium fruit, season total marketable tomato yield (all sizes and three harvests combined), and total culls (all three harvests combined). The UF/IFAS, CRF112/SNF56,

Table 2. 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 used to grow tomato in Immokalee, FL, during Fall 2011 and Fall 2012 growing seasons.

Treatments (kg·ha ⁻¹)	First harvest				First and second harvests				Season total harvest				
	Xlg ^z	Lrg	Med	Total	Xlg	Lrg	Med	Total	Xlg	Lrg	Med	Total	Cull
(Mg·ha ⁻¹)													
2011													
Grower standard	9.3	1.7	0.6	11.6	20.2	11.7	9.2 c ^y	41.1 c	21.6	15.0	14.6 b	51.2 b	9.8 b
UF/IFAS ^x	10.3	1.8	0.4	12.4	16.6	13.2	13.1 a	42.8 bc	17.6	16.4	24.7 a	58.6 a	15.3 a
CRF112/SNF56	11.2	1.9	0.6	13.6	20.6	15.5	12.0 ab	48.1 a	22.7	18.9	19.3 b	60.9 a	10.5 b
CRF168/SNF56	7.9	2.3	0.5	10.7	17.6	15.6	11.8 ab	45.1 ab	19.3	19.5	18.6 b	57.4 a	11.9 b
CRF224/SNF56	8.6	2.2	0.6	11.4	18.4	15.1	11.0 b	44.5 bc	19.6	18.9	18.9 b	57.4 a	15.4 a
<i>P</i> value	0.07	0.79	0.70	0.18	0.21	0.15	0.002	0.006	0.11	0.12	0.001	0.02	0.0002
Significance ^w	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
2012													
Grower standard	17.1 b	2.6	— ^v	19.6 cd	25.0 b	16.3	5.9	47.2	29.6	28.5	14.8	72.9	7.1
UF/IFAS	13.9 b	1.6	—	15.4 d	25.1 b	17.0	5.8	47.9	28.5	29.6	14.5	72.5	5.9
CRF112/SNF56	22.0 a	2.8	—	24.8 ab	30.1 a	14.2	6.1	50.5	31.7	23.9	13.2	68.9	8.2
CRF168/SNF56	22.6 a	3.9	—	26.5 a	31.2 a	16.3	5.6	53.1	35.3	27.5	12.5	75.3	6.1
CRF224/SNF56	17.6 b	3.3	—	20.8 bc	28.1 ab	19.0	4.6	51.7	32.4	31.1	12.6	76.1	7.6
<i>P</i> value	0.004	0.06	—	0.008	0.02	0.09	0.20	0.11	0.06	0.24	0.08	0.30	0.22
Significance	**	NS	—	**	*	NS	NS	NS	NS	NS	NS	NS	NS
Contrast linear (CRF only)	0.11	0.48	—	0.20	0.32	0.007	0.08	0.57	0.77	0.04	0.62	0.05	0.63
Significance	NS	NS	—	NS	NS	**	NS	NS	NS	*	NS	*	NS

^zXlg = extra-large (greater than 7.00 cm); Lrg = large (6.35 to 7.06 cm); Med = medium (5.72 to 6.43 cm).

^yWithin columns, means followed by different letters are significantly different according to Duncan's multiple range test, 5% level.

^xTotal nitrogen (N) rate includes 224 kg·ha⁻¹ N in the top mix and 34 kg·ha⁻¹ fertilizer applied after a leaching rain event on 28 Oct. 2011.

^wNS, *, ** Nonsignificant or significance at *P* ≤ 0.05, ≤ 0.01, or ≤ 0.001, respectively.

^vNo medium-sized tomatoes were harvested during the first harvest of 2012.

UF/IFAS = University of Florida/Institute of Food and Agricultural Science.

and CRF168/SNF56 treatments had the highest, whereas the grower standard treatment had the lowest medium tomato yield for FSHC. For FSHC total marketable yield, CRF112/SNF56 and CRF168/SNF56 had the highest tomato yields, although CRF168/SNF56 was not statistically different from CRF224/SNF56 or UF/IFAS. Both CRF224/SNF56 and UF/IFAS were not different from the grower standard treatment, which had the lowest FSHC total marketable yield. The UF/IFAS treatment had a greater season medium tomato yield than all other treatments. For season total harvest, all CRF and UF/IFAS treatments were greater than the grower standard treatment. The grower standard, CRF112/SNF56, and CRF168/SNF56 treatments had fewer cull fruit than the UF/IFAS and CRF224/SNF56 treatments. There were no differences for any tomato size or total marketable yield category in the first harvest (FH) or extra-large and large-sized categories in the FSHC and in-season total marketable harvests. When linear contrasts were performed among CRF treatments, there was no response to N rate [Table 2 (*P* ≤ 0.05)]. Thus, yield of the CRF treatments did not increase with increasing rate.

In 2012, there were differences in FH extra-large and total marketable yield (all sizes combined) and FSHC extra-large yield (*P* ≤ 0.05) (Table 2). The CRF112/SNF56 and CRF168/SNF56 treatments had greater FH and FSHC extra-large marketable tomato yields compared with grower standard, UF/IFAS, and CRF224/SNF56 treatments. The highest total FH marketable yields were

obtained by CRF168/SNF56 and CRF112/SNF56; however, CRF112/SNF56 did not significantly differ from CRF224/SNF56. No differences were found among other sizes and total season marketable and unmarketable (cull) yield. A linear response among CRF rates was significant for large-sized fruits in the FSHC, large-sized fruits for total season, and total season marketable yields indicating an increase in tomato yield with an increase in CRF N rate. There was no response to CRF N rates among other sizes and harvests. Overall, CRF112/SNF56 produced similar or higher marketable tomato yields at lower rates compared with both SF and CRF/SNF treatments.

Total marketable yields averaged 28.6% higher in 2012 than 2011 likely as a result of no leaching rain events during the 2012 season and only a single event during Fall 2011. Despite high rainfall during 2012, CRF112/SNF56 (168 kg·ha⁻¹ N) and CRF168/SNF56 (224 kg·ha⁻¹ N) produced greater early-season extra-large and total marketable yields with similar total season marketable yields compared with the grower standard, UF/IFAS, and CRF 224/SNF56 (280 kg·ha⁻¹ N). Therefore, increasing the N rate to 280 kg·ha⁻¹ N provided no advantage compared with 168 or 224 kg·ha⁻¹. Additionally, the fertilizer rate of 280 kg·ha⁻¹ N may have depressed yields as reported by Hochmuth and Cordasco (2008). Furthermore, Ozores-Hampton et al. (2012) showed reduced early-season tomato yields at SNF rates of 269 and 336 kg·ha⁻¹ during dry and wet seasons, respectively, which further supports the argument that application of N at 280 kg·ha⁻¹ may reduce yields. Because all

N fertilizer treatments were within or greater than the LTN sufficiency range throughout the season, N rate was not a limiting factor in production during Fall 2011 and 2012, which may further support CRF112/SNF56 as an acceptable tomato production N rate for this system. However, in 2012, increasing CRF N rates produced higher season total marketable yields indicating that CRF168/SNF56 will be an appropriate N rate.

Similarly to 2011, Ozores-Hampton et al. (2009) found no differences in first harvest marketable tomato yield when using the hybrid fertilizer system during a spring season with low rainfall. In contrast, in 2012 with high rainfall, the hybrid fertilizer system CRF224/SNF56 reduced FH extra-large and FH total yields. For tomatoes produced during the fall season, the earliest fruit harvested tend to provide the greatest return to the grower (Ozores-Hampton et al., 2012). Thus, CRF224/SNF56 is an inappropriate N rate because it lowered early fruit yield.

Postseason soil samples. There were interactions (*P* ≤ 0.05) between year and treatment; therefore, postseason soil sample data were presented by year and treatment. In 2011, CRF224/SNF56 had a greater NH₄⁺-N and urea-N content remaining in the soil post-season compared with the other treatments (Table 3). The grower standard, UF/IFAS, and CRF224/SNF56 had the highest NO₃⁻-N content remaining in the soil post-season, but CRF224/SNF56 did not significantly differ from CRF112/SNF56 and CRF168/SNF56. There were no differences in NH₄⁺-N, NO₃⁻-N, or urea-N content in the fertilizer prills among

Table 3. Total postseason soil test nitrogen (N) as ammonium-N ($\text{NH}_4^+\text{-N}$), nitrate-N ($\text{NO}_3^-\text{-N}$), and urea-N in the soil and controlled-release fertilizer (CRF) prills from five CRF/soluble nitrogen fertilizer (SNF) programs used to grow tomato in Immokalee, FL, during Fall 2011 and Fall 2012.

Treatment (kg·ha ⁻¹)	Soil ²			CRF prills			Total N	N release ³ (%)
	NH ₄ ⁺ -N	NO ₃ ⁻ -N	Urea-N	NH ₄ ⁺ -N	NO ₃ ⁻ -N	Urea-N		
	(kg·ha ⁻¹)							
2011								
Grower standard	4.8 b ^x	14.3 a	0.0 b	— ^w	—	—	19.0	—
UF/IFAS	2.6 b	15.9 a	0.1 b	—	—	—	18.6	—
CRF112/SNF56	4.8 b	2.7 b	0.9 b	1.5	2.1	0.4	12.4	96.4
CRF168/SNF56	4.7 b	1.9 b	0.4 b	1.2	2.0	0.2	10.5	97.8
CRF224/SNF56	8.5 a	8.9 ab	2.6 a	1.3	1.4	0.2	22.9	98.7
<i>P</i> value	0.006	0.016	0.004	0.78	0.52	0.64	0.12	—
Significance ^v	**	**	**	NS	NS	NS	NS	—
Contrast linear (CRF only)	0.040	0.10	0.047	0.59	0.31	0.49	0.039	—
Significance	*	NS	*	NS	NS	NS	*	—
2012								
Grower standard	7.5	10.4	0.0 b	—	—	—	17.9	—
UF/IFAS	6.2	3.6	0.0 b	—	—	—	9.8	—
CRF112/SNF56	6.7	3.0	0.0 b	1.7	10.1	0.0	21.5	89.5
CRF168/SNF56	5.2	3.3	0.1 a	2.3	13.8	0.0	24.7	90.4
CRF224/SNF56	4.3	6.4	0.1 a	3.0	26.5	0.1	40.4	86.8
<i>P</i> value	0.09	0.20	0.01	0.71	0.32	0.06	0.07	—
Significance	NS	NS	*	NS	NS	NS	NS	—
Contrast linear (CRF only)	0.13	0.29	0.037	0.43	0.16	0.027	0.20	—
Significance	NS	NS	*	NS	NS	*	NS	—

²An 8.9-cm wide × 20-cm deep cross-section of the tomato bed was taken from each treatment in all four replications. The cross-section was divided into three vertical sections, mixed and sampled. Each number is the mean of 12 measurements.

³N release = (total CRF N applied – N remaining in CRF prills)/total CRF N applied.

*Within columns, means followed by different letters are significantly different according to Duncan's multiple range test, 5% level.

^wNo CRF were used in the grower standard and University of Florida, Institute of Food and Agriculture Science (UF/IFAS) treatments; thus, analysis of variance was carried out on only CRF treatments for these columns.

^vNS, *, ** Nonsignificant or significance at $P \leq 0.05$ or ≤ 0.01 , respectively.

treatments that averaged 1.3, 1.8, and 0.3 kg·ha⁻¹, respectively. There were no differences in total N (TN) remaining in the soil postseason with an average of 16.7 kg·ha⁻¹ among the treatments. The linear contrasts were significant among the CRF N treatments, for $\text{NH}_4^+\text{-N}$ and urea-N in the soil, and for TN postseason. Therefore, increasing CRF N rates increased $\text{NH}_4^+\text{-N}$, urea-N, and TN remaining in the soil postseason samples. The CRFs released between 96.4% and 98.7% of their N during the season.

In 2012, soil urea-N contents from CRF224/SNF56 and CRF168/SNF56 were higher than that of the other treatments (Table 3). There were no differences among treatments in any other N category. Linear contrasts among CRF N treatments were significant for urea-N in soil and CRF prills indicating increasing CRF N rates will increase the amount of urea-N remaining post-season. The CRFs released between 86.8% and 90.4% of the N during the season.

Overall, there was more N remaining in the CRF treatments in 2012 as compared with 2011; however, greater N remained in the soluble treatments in 2011 as compared with 2012. Late-season rainfall (64% in Oct. 2012 vs. 59% in Sept. 2011) and a leaching rain event on 28 Oct. 2011 may explain the lower postseason N content in Fall 2011. Higher rainfall would have increased the water table depth and caused greater leaching as a result of drainage water movement from the field through irrigation ditches. Sato et al. (2009) documented movement of soluble nitrate

with the dropping of the water table depth. Potential N losses of 35% to 43% were found for tomato grown with seepage irrigation under similar soil, temperature, and rainfall conditions (Sato et al., 2012). Because the UF/IFAS treatment received an additional 34 kg·ha⁻¹ N after the leaching event to compensate for the loss of N, this additional N may have resulted in higher concentrations of N in the soil.

The postseason TN remaining in the soil was similar or lower than the values reported by Hendricks and Shukla (2011) and Sato et al. (2012) for seepage-irrigated tomatoes with similar rainfall and planting season. There was a similar amount of time between fertilizer placement and soil sampling dates, but average soil temperature during 2012 was 1.5 °C lower compared with that of 2011. Thus, the reduced season average soil temperature may explain the difference in CRF N release between the seasons. In a study by Simonne and Hutchinson (2005), CRFs did not release greater than 80% of the N during the season; thus, they determined that the CRFs were not suitable for use in chip stock potato. In this study, however, all CRFs released greater than 80% of the N during the season; therefore, using this metric, these CRFs are suitable for use in tomato. The release differences between this study and Simonne and Hutchinson (2005) were likely the result of temperature differences between fall and spring seasons.

Postharvest quality. There were interactions between year and N treatment for firmness

($P = 0.002$) and color ($P < 0.0001$) at the red ripe stage; thus, firmness and color data were presented by year (Table 4). In 2011, the firmest fruit (i.e., fruits with the least deformation) were from the grower standard, UF/IFAS, and CRF112/SNF56 treatments, whereas the softest fruit were from CRF224/SNF56. However, no differences were found between UF/IFAS and CRF168/SNF56 treatments. In 2012, there was no N treatment effect on fruit firmness that averaged medium to soft (2.2-mm deformation).

When linear contrasts were performed among CRF N treatments, there was no response to N rate in 2011 or 2012 [Table 4 ($P > 0.05$)]. The tomato firmness differences resulting from the N treatment in 2011 indicated softer fruit with higher CRF N rate; however, this difference was not evident in Fall 2012. Similar to 2012, no differences were found in tomato firmness during a spring study using six CRF treatments containing resin-coated urea and KNO_3 , methylene urea, and PSCU at two rates (Csizinszky, 1994).

In 2011, CRF224/SNF56 and CRF112/SNF56 treatments had the highest, whereas CRF168/SNF56 and grower standard treatments had the lowest color ratings (Table 4). In 2012, there were no differences in color ratings with an average of 5.9 across the treatments; however, there was a significant linear contrast effect among CRF treatments ($P = 0.002$), which indicated that color intensity increased with CRF N rate in 2012. Although tomato external color increased with increased CRF N rate in 2012, the UF/IFAS

Table 4. Postharvest firmness and color at the red ripe stage for tomato grown using five controlled-release fertilizer (CRF)/soluble nitrogen fertilizer (SNF) programs in Immokalee, FL, during Fall 2011 and Fall 2012.

Treatment (kg·ha ⁻¹)	Firmness ^z		Color stage ^y	
	2011	2012	2011	2012
Grower standard	2.6 c ^x	2.1	5.0 c	5.9
UF/IFAS ^w	3.0 bc	2.2	5.5 b	5.9
CRF112/SNF56	2.6 c	2.1	6.0 a	5.8
CRF168/SNF56	3.2 ab	2.2	5.0 c	5.8
CRF224/SNF56	3.4 a	2.2	6.0 a	6.0
P value	0.0002	0.89	0.0001	0.28
Significance ^v	***	NS	***	NS
Contrast linear (CRF only)	0.17	0.85	0.90	0.022
Significance	NS	NS	NS	*

^zDeformation in mm: very firm ≤ 0.7 mm; firm ≤ 1.4 mm; medium ≤ 2.1 mm; soft ≤ 2.8 mm; very soft ≥ 3.9 mm.

^yColor rating on a scale of 1 to 6, with 1 = mature green (unripe), 2 = breaker, 3 = turning 4 = pink, 5 = light red, 6 = red.

^xWithin columns, means followed by different letters are significantly different according to Duncan's multiple range test, 5% level.

^wUniversity of Florida, Institute of Food and Agriculture Science (UF/IFAS).

^vNS, *, **, *** Nonsignificant or significance at $P \leq 0.05$, ≤ 0.01 , or ≤ 0.001 , respectively.

and grower standard treatments did not statistically differ from the CRF treatments. Belnard et al. (2009) and Warner et al. (2004) found that tomato color was unaffected by N rate. Thus, the differences in tomato firmness and color were not related to N source or rate, but rather attributable to differences in tomato maturity, which is difficult to determine through non-destructive methods and the reason for different research methods during 2011 and 2012 (Maul, 1999). Therefore, the differences noted were not of practical commercial significance, but resulting from variations found in mature green-harvested fruit.

In conclusion, the bed temperatures encountered during both seasons were higher than those recommended by the CRF manufacturer, potentially shortening the N release duration during the season. However, there were no detrimental effects on yield or LTN concentration as a result of the possibility of accelerated N release. The hybrid fertility system containing CRF/SNF produced similar or greater marketable tomato yields and lower residual soil N postseason with CRF112/SNF56 (168 kg·ha⁻¹) or CRF168/SNF56 (224 kg·ha⁻¹) compared with the grower standard rate (280 kg·ha⁻¹ N), CRF224/56SNF (280 kg·ha⁻¹ N), or UF/IFAS (224 kg·ha⁻¹ N), which is a 46% and 25% reduced N rate, respectively. All treatments produced acceptable fruit firmness and color at the red ripe stage. The recommended N rate using a hybrid fertilizer system containing 112 to 168 kg·ha⁻¹ CRF-N and 56 kg·ha⁻¹ SNF produced acceptable tomato yield and quality with minimum postseason soil N, minimizing the potential losses of N to the environment.

Literature Cited

Bartnick, B., G. Hochmuth, J. Hornsby, and E. Simonne. 2005. Water quality/quantity best management practices for Florida vegetable and agronomic crops. Florida Dept. Agr. Consumer Serv., Tallahassee, FL.

Belnard, C., H. Gautier, F. Bourgaud, D. Grasselly, B. Navez, C. Caris-Veyrat, M. Weiss, and M.

Geïnard. 2009. Effects of low nitrogen supply on tomato (*Solanum lycopersicum*) fruit yield and quality with special emphasis on sugars, acids, ascorbate, carotenoids, and phenolic compounds. *J. Agr. Food Chem* 57:4112–4123.

Bonczek, J.L. and B.L. McNeal. 1996. Specific-gravity effects on fertilizer leaching from surface sources to shallow water tables. *Soil Sci. Soc. Amer. Proc.* 60:978–985.

Carson, L.C. and M. Ozores-Hampton. 2013. Factors affecting nutrient availability, placement, rate, and application timing of controlled-release fertilizers for Florida vegetable production using seepage irrigation. *HortTechnology* 23: 553–562.

Carson, L.C., M. Ozores-Hampton, and K.T. Morgan. 2012. Effect of controlled-release fertilizer on tomatoes grown with seepage irrigation in Florida sandy soils. *Proc. Fla. State Hort. Soc.* 125:164–168.

Carson, L.C., M. Ozores-Hampton, and K.T. Morgan. 2013. Nitrogen release from controlled-release fertilizers in seepage-irrigated tomato production in south Florida. *Proc. Fla. State Hort. Soc.* 126:in press.

Csizinszky, A.A. 1989. Effect of controlled (slow) release nitrogen sources on tomato, *Lycopersicon esculentum* Mill. cv. Solar Set. *Proc. Fla. State Hort. Soc.* 102:348–351.

Csizinszky, A.A. 1992. Evaluation of methylene urea for fresh-market tomato with seepage irrigation. *Proc. Fla. State Hort. Soc.* 105:370–372.

Csizinszky, A.A. 1994. Yield response of bell pepper and tomato to controlled-release fertilizers on sand. *J. Plant Nutr.* 7:1535–1549.

Diaz-Perez, J.C. and K.D. Batal. 2002. Colored plastic film mulches affect tomato growth and 409 yield via changes in root-zone temperature. *J. Amer. Soc. Hort. Sci.* 127:127–135.

Engelsjord, M., O. Fostad, and B. Singh. 1996. Effects of temperature on nutrient release from slow-release fertilizers. *Nutr. Cycl. Agroecosyst.* 46:179–187.

Florida Automated Weather Network (FAWN). 2013. Archived weather data. UF/IFAS, Gainesville, FL. 7 June 2013. <<http://fawn.ifas.ufl.edu/data/>>.

Hendricks, G.S. and S. Shukla. 2011. Water and nitrogen management effects on water and nitrogen fluxes in Florida flatwoods. *J. Environ. Qual.* 40:1844–1856.

Hochmuth, G. and K. Cordasco. 2008. A summary of N, P, K research with tomato in Florida.

Univ. Florida, Inst. Food Agr. Sci., Electronic Data Info. Source. HS759. 31 July 2012. <<http://edis.ifas.ufl.edu/cv236>>.

Hochmuth, G., D. Maynard, C. Vavrina, E. Hanlon, and E. Simonne. 2010. Plant tissue analysis and interpretation for vegetable crops in Florida. Univ. Florida, Inst. Food Agr. Sci., Electronic Data Info. Source, HS964. 26 Oct. 2013. <<http://edis.ifas.ufl.edu/ep081>>.

Huett, D.O. and B.J. Gogel. 2000. Longevities and nitrogen, phosphorus, and potassium release patterns of polymer-coated controlled-release fertilizers at 30°C and 40°C. *Commun. Soil Sci. Plant Anal.* 31:959–973.

Liu, G.D., E.H. Simonne, and G.J. Hochmuth. 2012. Soil and fertilizer management for vegetable production in Florida, p. 3–27. In: Olson, S.M. and B.S. Santos (eds.). *Vegetable production handbook for Florida*. IFAS/UF, Gainesville, FL.

Maul, F. 1999. Flavor of fresh market tomato (*Lycopersicon esculentum* Mill.) as influenced by harvest maturity and storage temperature. PhD diss., University of Florida, Gainesville, FL.

Mulvaney, R.L. and J.M. Bremner. 1979. A modified diacetyl monoxime method for colorimetric determination of urea in soil extracts. *Commun. Soil Sci. Plant Anal.* 10:1163–1170.

Muñoz-Arboleda, F., R.S. Mylavarapu, C.M. Hutchinson, and K.M. Portier. 2006. Root distribution under seepage-irrigated potatoes in northeast Florida. *Amer. J. Potato Res.* 83: 463–472.

Natural Resources Conservation Service. 2012. Web soil survey. 12 July 2013. <<http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm>>.

Olson, S.M., W.M. Stall, G.E. Vallad, S.E. Webb, S.A. Smith, E.H. Simonne, E.J. McAvoy, and B.M. Santos. 2012. Tomato production in Florida, p. 321–344. In: Olson, S.M. and B. Santos (eds.). *Vegetable production handbook for Florida*. Vance, Lenexa, KS.

Ozores-Hampton, M., E. Simonne, F. Roka, K. Morgan, S. Sargent, C. Snodgrass, and E. McAvoy. 2012. Nitrogen rates effects on the yield, nutritional status, fruit quality, and profitability of tomato grown in the spring with subsurface irrigation. *HortScience* 47:1129–1133.

Ozores-Hampton, M.P., E.H. Simonne, K. Morgan, K. Cushman, S. Sato, C. Albright, E. Waldo, and A. Polak. 2009. Can we use controlled release fertilizers (CRF) in tomato production? *Proc. Fla. Tomato Inst.* PRO526:10–13.

Sargent, S.A., J.K. Brecht, and T. Olczyk. 2005. Handling Florida vegetables series: Round and roma tomato types. Institute of Food and Agriculture Sciences, University of Florida, Gainesville, FL SS-VEC-928.

Sato, S. and K.T. Morgan. 2008. Nitrogen recovery and transformation from a surface or sub-surface application of controlled-release fertilizer on a sandy soil. *J. Plant Nutr.* 31:2214–2231.

Sato, S., K.T. Morgan, M. Ozores-Hampton, K. Mahmood, and E.H. Simonne. 2012. Nutrient balance and fertilizer use efficiency in sandy soils cropped with tomatoes under seepage irrigation. *Soil Sci. Soc. Amer. J.* 76:1867–1876.

Sato, S., K.T. Morgan, M. Ozores-Hampton, and E.H. Simonne. 2009. Spatial and temporal distribution in sandy soils with seepage irrigation: I. Ammonium and nitrate. *Soil Sci. Soc. Amer. J.* 73:1044–1052.

Simonne, E.H. and C.M. Hutchinson. 2005. Controlled-release fertilizers for vegetable production in the era of best management

- practices: Teaching new tricks to an old dog. *HortTechnology* 15:36–46.
- Slater, J.V. 2010. Official publication AAPFCO. Association of American Plant Food Control Officials, West Lafayette, IN.
- Smajstrla, A.G. and R. Muñoz-Carpena. 2011. Simple water level indicator for seepage irrigation. Institute of Food and Agriculture Sciences, University of Florida, Gainesville, FL. AE085.
- Trenkel, M.E. 2010. Slow- and controlled release and stabilized fertilizers: An option for enhancing nutrient use efficiency in agriculture. 2nd Ed. IFA, Paris, France.
- U.S. Department of Agriculture. 1997. United States standards for grade of fresh tomatoes. U.S. Dept. Agr. Agr. Mktg. Serv., Washington, DC. 18 Dec. 2013. <<http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5050331>>.
- U.S. Department of Agriculture. 2013. Vegetable 2012 summary. U.S. Dept. Agr., Washington, DC.
- Warner, J., T.Q. Zhang, and X. Hao. 2004. Effects of nitrogen fertilization on fruit yield and quality of processing tomatoes. *Can. J. Plant Sci.* 84:865–871.
- Zheng, D., E.R. Hunt, Jr., and S.W. Running. 1993. A daily soil temperature model based on air temperature and precipitation for continental applications. *Clim. Res.* 2:183–191.