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Evaluation of Controlled-Release Fertilizers for Northeast Florida Chip Potato Production

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ABSTRACT

Controlled-release fertilizers (CRF) were compared with ammonium nitrate (AN) in a potato (*Solanum tuberosum* L.) production study at the University of Florida farm in Hastings, FL, in 2002. Treatments were no nitrogen (No-N), AN, and nine CRFs at 146 kg ha^{-1} N and 225 kg ha^{-1} N. CRF7 (146 kg ha^{-1} N) resulted in highest total and marketable yields at 33.7 MT ha^{-1} and 29.4 MT ha^{-1}, respectively. Tubers from the AN (225 kg ha^{-1} N) and CRF9 (225 kg ha^{-1} N) treatments had the highest specific gravity at 1.073. Nitrogen removal efficiency was highest in plants in CRF1 (43.0%) and CRF7 (47.3%) plots. Both were significantly higher than AN-treated plants. At 39 days after planting, NO_3-N and NH_4-N concentrations in lysimeter water samples were significantly higher in AN treatments. Leaf tissue N concentrations were sufficient throughout the growing season in all treatments except No-N.

Keywords: polymer-coated urea, nutrient-use efficiency, leaching, chips, crisps

INTRODUCTION

In 2002, the Tri-County Agricultural Area (Putnam, St. Johns, and Flagler counties, TCAA) of northeastern Florida produced nearly half of Florida's \$130 million per year, 15,000 ha potato (*Solanum tuberosum* L.) crop (Bronson, 2002). In Florida potato production, a perched water table is maintained using sub-surface irrigation between 45 and 60 cm below the surface of the potato bed (Hutchinson et al., 2002a). Soils in the TCAA are sandy, with a low water-holding capacity (1.9 cm per 30 cm soil) (Hutchinson et al., 2002a). This,

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together with the shallow root system of potato and the possibility of excessive seasonal rains, increases the potential for movement of water-soluble plant nutrients into watersheds.

State and local regulatory agencies in cooperation with growers in the TCAA have developed best management practices (BMP) to reduce nitrate-leaching potential in the TCAA. The BMP program is part of the TCAA Water Quality Protection Cost Share Program, which is managed by the St. Johns River Water Management District (SJRWMD) (Livingston-Way, 2002). This program works with growers to implement BMPs by partially offsetting implementation costs of new practices. The TCAA BMP nitrogen (N) rate is 225 kg ha^{-1} N, based on recommendations by the University of Florida's Institute of Food and Agricultural Science (UF/IFAS) (Hochmuth et al., 2002). This is a reduction of 60 kg ha^{-1} N below the TCAA grower average N rate of approximately 285 kg ha^{-1} N.

Controlled-release fertilizers (CRF) are one technology that may allow growers to maintain profitable potato yields while reducing the potential for negative N impacts on the environment. CRFs are fertilizers formulated to provide nutrients to plants at times and in quantities needed for proper growth. CRFs may improve N-use efficiencies, thereby allowing reduced N rates below the BMP rate. CRFs have been used successfully for production of 'Centennial' potatoes on sandy soils in Colorado (Shoji et al., 2001), 'Russet Burbank' potatoes on loamy sands in Minnesota (Zvomuya and Rosen, 2001; Zvomuya et al., 2003), and 'Atlantic' potatoes on sandy soils in Florida (Hutchinson and Simonne, 2001; Hutchinson et al., 2003). These trials resulted in a combination of comparable or increased tuber yields and reduced N losses to the environment. CRF programs have reduced nitrate leaching by up to 49% in sandy soils and increased nutrient-use efficiency (NUE) in potato production compared with use of urea (Zvomuya et al., 2003).

The objective of this research was to evaluate potato tuber production and quality, N removal by the crop, and nitrate (NO_3-N) and ammonium (NH_4-N) leaching when soil was fertilized with CRF and ammonium nitrate sources.

MATERIALS AND METHODS

Potato Production

The experiment was conducted at the University of Florida's Plant Science Research and Education Unit (PSREU) in Hastings, FL, on an Ellzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf; sand 90%–95%, <2.5% clay, <5% silt). Potato rows were on 102 cm centers. Irrigation furrows were spaced every 16 rows. Experimental plots were four rows wide by 6.1 m. Subsurface irrigation was used to maintain the water table between 45 and 60 cm below the top of the potato row.

'Atlantic' potato seed tubers were cut to approximately 71 g seed pieces. Seed pieces were dusted with fungicide (1.1 g a.i. fludioxonil and 21.8 g a.i. mancozeb per 45.4 kg seed pieces; Maxim MZ, Syngenta Crop Protection, Inc. Greensboro, NC) prior to planting. Potato seed pieces were planted at a 20 cm in-row spacing on February 14, 2002.

Pesticide applications were made following University of Florida Extension recommendations (Hochmuth et al., 2002). Soil was fumigated with 1,3-dichloropropene (Telone II, 56 L ha^{-1}, Dow Chemical Company, Indianapolis, IN) in early January prior to planting. Aldicarb (Temik, 22.5 kg ha^{-1}, Bayer Chemical Company, Kansas City, MO) was applied in furrow at planting. Metribuzin (Sencor, 2.9 L ha^{-1}, Bayer Chemical Company, Kansas City, MO) was broadcast at hilling (approximately 20 days after planting, DAP) for weed control. Fungicides were applied as needed throughout the season for control of early and late blight, as were insecticides for insect control.

The center two rows of each plot were mechanically harvested on June 4, 2002 with commercial equipment (100 DAP). Potatoes were washed and graded into five size classes as defined by USDA grading standards (USDA, 1991). Specific gravity was measured by the weight in air/weight in water method (Edgar, 1951).

Fertilizer Treatments

Treatments consisted of a no-fertilizer control and 10 N sources, ammonium nitrate (AN) and 9 CRF, each at two rates (146 and 225 kg ha^{-1} N). The N rates represented 65% and 100% of the recommended BMP rate (Table 1). CRFs were selected based on their nutrient-release characteristics and how they matched the need of the potato crop. Nitrogen source in all CRFs was urea. Blended treatments (Scotts blends 1 through 3) received half the total N from each product. All fertilizer treatments were incorporated 1 d before planting. Based on soil test results, 34 kg P ha^{-1} (76 kg P_2O_5 ha^{-1}) and 168 kg K ha^{-1} (202 kg K_2O ha^{-1}) were incorporated into all treatment plots prior to planting.

Soil Analysis

A composite soil sample (20, 30 cm cores) was taken before planting from the planting area, air-dried, and analyzed by the University of Florida's Analytical Research Laboratory (ARL) for soil pH (1:2 v/v method), nitrate- and ammonium-nitrogen concentrations, phosphorus (P), calcium (Ca), magnesium (Mg) (Mehlich-1 method), electrical conductivity (EC) (1:2 w/v method), and soil organic matter (OM) (Walkley Black method). At the end of the growing season, a composite sample of six 30 cm cores was taken from each plot and prepared and analyzed as described.

Table 1
Fertilizer treatments, manufacturers, and rates for conventional and controlled-release fertilizers tested in Hastings, FL, in 2002

Treatment	Manufacturer	Formulation[1]	Rate (kg ha^{-1} N)
TRT-1	—	No-nitrogen control	0
TRT-2	Gator Fertilizer[2]	Ammonium nitrate (34-0-0)[7]	146
TRT-3	Gator Fertilizer	Ammonium nitrate (34-0-0)	225
TRT-4	Scotts Co.[3]	(37-0-0) + (43-0-0)	146
TRT-5	Scotts Co.	(37-0-0) + (43-0-0)	225
TRT-6	Scotts Co.	(37-0-0) + (11-11-11)	146
TRT-7	Scotts Co.	(37-0-0) + (11-11-11)	225
TRT-8	Scotts Co.	(43-0-0) + (38-0-0)	146
TRT-9	Scotts Co.	(43-0-0) + (38-0-0)	225
TRT-10	Helena Chemical[4]	(40-0-0)	146
TRT-11	Helena Chemical	(40-0-0)	225
TRT-12	Helena Chemical	(40-0-0)	146
TRT-13	Helena Chemical	(40-0-0)	225
TRT-14	Haifa Nutritech[5]	(40-0-0)	146
TRT-15	Haifa Nutritech	(40-0-0)	225
TRT-16	—[6]	(41.1-0-0)	146
TRT-17	—	(41.1-0-0)	225
TRT-18	—	(40.3-0-0)	146
TRT-19	—	(40.3-0-0)	225
TRT-20	—	(41.8-0-0)	146
TRT-21	—	(41.8-0-0)	225

2[1]50% of the total N from each product in blended treatments.
[2]Hastings, FL; [3]Marysville, OH; [4]Collierville, TN; [5]Altamonte Springs, FL; [6]Names withheld in compliance with agreements between the University of Florida and manufacturers.
[7]Percent N-P_2O_5-K_2O.

Water Sampling and Analysis

One suction lysimeter was buried to a 30 cm depth below the top of the potato row in each plot. At two-week intervals during the season, a vacuum of approximately 50 kPa was applied to each lysimeter. After 24 h, a water sample was taken. Well casings (PVC pipe, 10 cm diameter by 120 cm long) were buried at a depth of 100 cm below the soil surface in each plot to access the perched water table. The water table was sampled at two-week intervals during the growing season. Water samples were stored at $-5°C$ until analyzed for NO_3-N and NH_4-N concentrations (EPA 353.2 and EPA 353.1 methods, respectively) at the ARL (Mylavarapu and Kennelley, 2002).

Tissue Sampling and Analysis

Two recently matured leaves were randomly sampled from plants in the center two rows of each plot at two-week intervals. Their petioles were separated from the leaf blades, combined, pressed, and analyzed for fresh sap NO_3-N concentration using a Cardy ion-specific electrode meter (Spectrum Technologies, Plainfield, IL). Four additional leaf petiole samples from each plot were combined and dried at 70°C until a constant weight was measured, ground in a Wiley mill to pass a 20-mesh sieve, and analyzed for total Kjeldahl nitrogen (TKN) at the ARL (Mylavarapu and Kennelley, 2002). At 61 DAP, when the majority of plants were flowering, the leaves and stems from one plant selected randomly from each plot were separated, dried, weighed, and ground. At harvest (104 DAP), four tubers from each plot were diced into 1 cm^3 cubes, dried, weighed, and ground. Leaf, stem, and tuber tissue all were analyzed for TKN at the ARL (Mylavarapu and Kennelley, 2002).

Nutrient-Removal Efficiency

Nutrient-removal efficiency (NRE) was calculated after the method used by Zvomuya et al. (2003) by the following equation:

$$\mathrm{NRE} = 100 \times (\mathrm{N}_{\mathrm{treat}} - \mathrm{N}_{\mathrm{control}})/\mathrm{N}_{\mathrm{applied}}$$

where N_{treat} represents the amount of N removed in tubers from a given fertilizer treatment. $N_{control}$ is N removed in tubers from the no-fertilizer control plot. Last, $N_{applied}$ is the amount of N applied as fertilizer.

Statistical Analysis

The experiment was arranged in a randomized complete-block design with four replications. All analyses were performed using SAS ANOVA software (SAS, 1999). Treatment means were separated using Fisher's protected least significant difference mean separation test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Temperature and Precipitation

Temperature and precipitation were generally favorable for potato production throughout the season, though the level of precipitation (15.85 cm) was lower than the historical average of 27.41 cm (Hastings REC Archived Data, 1954–2002). PSREU-Hastings research farm received most of its precipitation during three events occurring on 9 DAP (3.6 cm), 17 DAP (3.3 cm), and 92 DAP (3.0 cm) (FAWN, 2002). The impact of such rain early in the season would be expected to be greater with soluble fertilizer (AN) than with the CRF treatments.

On 15, 16, and 20 DAP, night temperatures dropped below 0°C (Hastings REC Archived Data, 1954–2002). To protect the plants from freezing, they were covered with soil at 15 DAP and uncovered at 17 DAP, a standard practice for Florida potato production. Though this step resulted in minor mechanical damage, the low temperatures would have resulted in more plant damage.

Tuber Production

As expected, plants in the No-N treatment produced the lowest marketable yield (18.4 MT ha^{-1}). Plants under the TRT-16 (146 kg ha^{-1} N) treatment had the highest total and marketable yields at 33.7 MT ha^{-1} and 29.4 MT ha^{-1}, respectively (Table 2). Potatoes under TRT-16 and TRT-21 (225 kg ha^{-1} N) produced significantly higher marketable yields than plants under TRT-2 (AN, 146 kg ha^{-1} N), though not significantly more than TRT-3 (AN, 225 kg ha^{-1} N). Within each fertilizer product, there was no significant difference in yield between rates. Thus, CRFs used at the lower fertilizer rate may reduce N available for leaching without compromising yield compared with conventional fertilizer at the BMP rate. Potatoes under TRT-4, TRT-5, TRT-8, TRT-9, and TRT-16 through TRT-21 produced similar quantities and sizes of tubers as those under AN (both rates). It should be remembered, however, that the AN treatments did not represent grower standards in that they were applied all at planting instead of in split applications.

Plants under TRT-2 (AN, 146 kg ha^{-1} N) produced the highest percentage of small tubers (Table 2). However, plant size was not statistically different from that of plants under all other fertilized treatments (Table 3). There were significantly more culled tubers with 146 kg ha^{-1} N than with 225 kg ha^{-1} N across all products (data not shown). There was no advantage of one CRF product over another with respect to external tuber quality. Thus, the evaluated CRFs, even at reduced rates, appear to provide N to plants in quantities sufficient to ensure comparable marketable tuber yields to AN at the 224 kg ha^{-1} N BMP and recommended rates.

Specific Gravity

High tuber specific gravity (SG) is desirable for processing potatoes because there is less water in a given tuber's weight, which increases the chipping yield. Thus, having high SG improves production efficiency at the potato-processing plant. Tuber SG was highest under TRT-3 (AN, 225 kg ha^{-1} N) and TRT-21 (225 kg ha^{-1} N) at 1.073 (Table 2). The lowest SG potatoes were under the

Table 2
Production statistics for 'Atlantic' potatoes grown under AN and CRF treatments in Hastings, FL, in 2002

Treatment	N (kg ha^{-1})	Total yield (MT ha^{-1})	Marketable yield[1] (MT ha^{-1})	Size class range (%)[2]		Specific gravity
				2–4	3–4	
TRT-1	0	22.1 c	18.4 d	92.7 a–e	18.2	1.064 h
TRT-2	146	30.0 ab	24.5 c	89.0 f	19.9	1.071 a–c
TRT-3	225	30.1 ab	26.3 a–c	90.8 d–f	24.6	1.073 ab
TRT-4	146	31.8 ab	27.0 a–c	92.0 b–e	25.7	1.070 b–e
TRT-5	225	31.5 ab	27.3 a–c	92.3 a–e	24.3	1.070 c–f
TRT-6	146	28.9 b	24.5 c	91.7 c–e	21.8	1.067 f–h
TRT-7	225	30.5 ab	25.6 bc	90.3 ef	21.5	1.066 gh
TRT-8	146	31.8 ab	27.4 a–c	91.8 b–e	22.5	1.070 b–e
TRT-9	225	32.4 ab	27.9 a–c	91.4 c–f	30.4	1.072 a–c
TRT-10	146	31.8 ab	27.0 a–c	92.4 a–e	22.0	1.069 c–f
TRT-11	225	29.8 b	25.9 bc	91.3 c–f	24.1	1.071 a–c
TRT-12	146	29.9 ab	25.4 bc	94.5 a	28.4	1.068 d–g
TRT-13	225	29.9 b	25.9 bc	93.3 a–c	23.0	1.070 b–e
TRT-14	146	28.7 b	24.7 c	94.5 a	26.0	1.068 e–g
TRT-15	225	29.2 b	25.6 bc	94.2 ab	29.6	1.070 b–e
TRT-16	146	33.7 a	29.4 a	93.4 a–c	28.0	1.070 b–e
TRT-17	225	30.7 ab	26.9 a–c	92.3 a–e	24.7	1.071 a–c
TRT-18	146	31.8 ab	27.5 a–c	92.3 a–e	26.8	1.071 a–c
TRT-19	225	31.2 ab	27.0 a–c	91.7 c–e	23.4	1.069 c–g
TRT-20	146	31.5 ab	27.7 a–c	93.0 a–d	30.0	1.071 a–d
TRT-21	225	31.9 ab	28.9 ab	94.5 a	29.7	1.073 a
LSD[3]		3.9	3.5	2.5	ns	0.003
p-value		<0.01	<0.01	<0.01	0.35	<0.01

[1]Marketable yield: size classes 2–4.

[2]Size classes: 1 = <4.8 cm, 2 = 4.8 cm–6.4 cm, 3 = 6.4 cm–8.3 cm, 4 = 8.3 cm–10.2 cm, 5 = >10.2 cm.

[3]Means separated within columns with Fisher's protected least significant difference means separation test at $p \leq 0.05$.

No-N and TRT-6–7 (146 and 225 kg ha^{-1} N, respectively) treatments at 1.064, 1.066, and 1.067, respectively. Generally, SG values in this experiment were low. An average SG for 'Atlantic' potatoes at the PSREU-Hastings research farm is 1.079 (Hutchinson et al., 2002b). Tubers from the BMP N-rate plots had significantly higher SG than tubers from the reduced N-rate plots within each fertilizer source. Based on SG data, TRT-9 (225 kg ha^{-1} N), TRT-11 (225 kg ha^{-1} N), TRT-17 (225 kg ha^{-1} N), TRT-18 (146 kg ha^{-1} N), and TRT20–21 performed as well as the AN treatments (either rate). As with the production

Table 3
Nitrogen removal by plant tissue type within each plant and on a per-hectare basis under AN and CRF treatments in Hastings, FL, in 2002

		N plant^{-1}		kg N ha^{-1}		
Treatment	N kg ha^{-1}	Leaf g kg^{-1}	Stem g kg^{-1}	Leaf + stem kg ha^{-1}	Tuber kg ha^{-1}	Total NRE (%)[1]
TRT-1	0	0.568 c	0.081 g	31.4 d	51.1 i	—
TRT-2	146	1.225 a–c	0.330 a–e	75.3a–c	76.5h	22.3 c–g
TRT-3	225	1.470 a	0.428 a	91.9 ab	93.5 c–h	24.1 c–g
TRT-4	146	1.284 a–c	0.301 a–f	76.7 a–c	94.8 c–h	33.7 b–d
TRT-5	225	1.216 a–c	0.367 a–d	76.6 a–c	103.9 b–e	27.3 c–g
TRT-6	146	0.930 a–c	0.208 c–g	55.1 b–d	78.2 gh	19.2 fg
TRT-7	225	1.571 a	0.379 a–c	94.4 ab	86.8 e–h	17.8 g
TRT-8	146	1.666 a	0.402 ab	99.6 a	88.9 d–h	31.3 b–e
TRT-9	225	1.194 a–c	0.286 a–f	71.7 a–d	108.9 a–c	29.9 c–f
TRT-10	146	1.001 a–c	0.192 d–g	57.8 a–d	114.1 ab	43.0 ab
TRT-11	225	1.184 a–c	0.241 b–g	69.0 a–d	101.5 b–e	23.8 c–g
TRT-12	146	0.704 bc	0.133 fg	40.5 cd	81.7 f–h	24.7 c–g
TRT-13	225	1.043 a–c	0.198 d–g	60.1 a–d	96.4 b–g	21.8 d–g
TRT-14	146	1.004 a–c	0.156 e–g	56.1 b–d	81.6 f–h	21.4 e–g
TRT-15	225	1.124 a–c	0.210 c–g	64.6 a–d	95.1 c–h	24.0 c–g
TRT-16	146	1.404 ab	0.298 a–f	82.4 a–c	122.5 a	47.3 a
TRT-17	225	1.096 a–c	0.297 a–f	67.4 a–d	110.2 a–c	27.7 c–g
TRT-18	146	1.165 a–c	0.255 a–g	68.7 a–d	104.1 a–e	34.2 bc
TRT-19	225	1.343 ab	0.332 a–d	81.1 a–c	97.9b–f	27.2 c–g
TRT-20	146	0.957 a–c	0.262 a–f	59.0 a–d	105.6 a–d	32.9 b–e
TRT-21	225	1.486 a	0.337 a–d	88.3 ab	108.9 a–c	27.7 c–g
LSD[2]		0.734	0.175	17.0	7.5	12.0
p-value		<0.01	<0.01	0.02	<0.01	<0.01

[1]Fertilizer nitrogen removal efficiency: $100 \times (N_{treat} - N_{control})/N_{applied}$.
[2]Means separated within columns with the Fisher's protected least significant difference mean separation test at $p \leq 0.05$.

data on tuber yields, SG data indicate that many of the CRF treatments produced potatoes with tuber SG similar to that under the conventional AN fertilizer.

Tissue Analysis

There were no significant differences measured in leaf, stem, or leaf + stem dry weights for potatoes with any of the treatments sampled at full flower, indicating similar potato plant sizes between treatments (data not shown). However, tuber dry weights varied at harvest, with TRT-10 (146 kg ha^{-1} N; 133.9 g plant^{-1}) significantly higher than for the No-N (82.3 g plant^{-1}), TRT-6 (146 kg ha^{-1}

N; 110.4 g plant^{-1}), and TRT-14 (146 kg ha^{-1} N; 108.0 g plant^{-1}) treatments. Tuber dry weight per plant was highly related, as expected, to total tuber yield.

Fertilizer treatment had no significant effect on plant sap NO_3-N measurements at any sampling date (data not shown). At 34 DAP, NO_3-N sap concentrations under all treatments except the No-N treatment were above the recommended range for Florida potato production (Hochmuth et al., 2002). Sap nitrate concentrations for plants under the No-N treatment were within the sufficiency range early in the season. By 47 DAP, they became deficient and remained so for the duration of the season. Plant sap nitrate concentrations under all fertilized treatments gradually declined over the course of the season to a 713 mg L^{-1} average. They were in the recommended range of 600–900 mg L^{-1} late in the growing season (Hochmuth et al., 2002). Sap nitrate under CRF treatments was similar to AN at the BMP rate.

Nitrogen-Removal Efficiency

Tubers from plants under all fertilized treatments removed significantly more N from the field than tubers from plants under the No-N treatment (51.1 kg ha^{-1} N) (Table 3). Plants under TRT-10 (146 kg ha^{-1} N) and TRT-16 (146 kg ha^{-1} N) had the highest nitrogen-removal efficiency (NRE) at 43.0% and 47.3%, respectively, significantly higher than potatoes under TRT-3 (AN, 225 kg ha^{-1} N; 24.12%) (Table 3). With the exception of AN, TRT-14, and TRT-15, NRE values decreased with an increase in fertilizer rate. As anticipated, some CRFs released nutrients more efficiently than AN, enabling plants to recover a higher percentage of N during the growing season. Low NRE values with some CRFs merit further evaluation. Low NREs could be caused by lockout (coated prills never release the fertilizer) or improper release rates (release interval too short/too long).

Lysimeter and Well Nitrogen

Significantly higher concentrations of NO_3-N were observed in the soil solution from suction lysimeters with TRT-2 (AN, 146 kg ha^{-1} N; 127 mg L^{-1} NO_3-N) and TRT-3 (AN, 225 kg ha^{-1} N; 172 mg L^{-1} NO_3-N) than with any CRF at 39 DAP (Table 4). At 53 DAP, lysimeter NO_3-N concentration was 66 mg L^{-1} under TRT-3 (AN, 225 kg ha^{-1} N). This concentration was numerically the highest, but not statistically different from that under TRT-16 (146 kg ha^{-1} N; 38 mg L^{-1}), TRT-19 (225 kg ha^{-1} N; 36 mg L^{-1}), or TRT-20 (146 kg ha^{-1} N; 50 mg L^{-1}). After 53 DAP, lysimeter nitrate concentrations gradually decreased over the remaining measurements and no significant differences were observed with any of the treatments. Notably, NO_3-N in lysimeters in CRF-fertilized plots decreased steadily over the season rather than remaining relatively constant. This result may suggest that either early release was too high or that there was

Table 4
Concentration of soil water NO_3-N (mg L^{-1}) in lysimeters 30 cm below potato bed under AN and CRF treatments in Hastings, FL, in 2002

Treatment	N (kg ha^{-1})	Days after planting				
		39	53	67	81	95
		NO_3-N (mg L^{-1})				
TRT-1	0	25.9 b	11.0 bc	12.3	8.5	5.1
TRT-2	146	127.5 a	21.6 bc	9.5	2.8	2.8
TRT-3	225	172.5 a	66.4 a	29.0	15.9	15.6
TRT-4	146	33.3 b	13.8 bc	5.4	1.6	8.2
TRT-5	225	39.7 b	7.9 c	4.0	2.0	1.7
TRT-6	146	25.2 b	11.1 bc	8.5	16.9	22.5
TRT-7	225	42.5 b	14.1 bc	12.1	0.5	0.5
TRT-8	146	32.5 b	6.6 c	3.2	3.9	3.2
TRT-9	225	32.0 b	19.7 bc	11.3	10.7	9.1
TRT-10	146	53.6 b	24.3 bc	30.2	16.2	13.1
TRT-11	225	44.5 b	14.4 bc	14.3	5.6	6.3
TRT-12	146	41.7 b	32.7 a–c	29.6	12.5	4.9
TRT-13	225	34.0 b	8.0 c	11.5	17.2	13.7
TRT-14	146	22.1 b	9.5 bc	6.5	2.2	2.2
TRT-15	225	45.1 b	23.2 bc	13.8	15.0	7.0
TRT-16	146	62.8 b	38.1 a–c	30.5	14.0	7.3
TRT-17	225	52.5 b	13.0 bc	7.2	12.9	14.0
TRT-18	146	39.5 b	18.4 bc	10.1	3.7	2.3
TRT-19	225	44.1 b	35.5 a–c	15.3	9.6	5.2
TRT-20	146	66.9 b	50.4 ab	22.7	20.1	31.5
TRT-21	225	37.0 b	13.9 bc	11.2	9.6	6.7
LSD[1]		50.7	41.4	ns	ns	ns
p-value		< 0.01	0.03	0.53	0.55	0.27

[1]Means separated within columns with Fisher's protected least significant difference mean separation test at $p \leq 0.05$.

a substantial quantity of improperly coated or broken prills, resulting in high initial N release. However, the data also clearly indicate that any CRF is better than AN for reduction in NO_3-N in the soil solution.

Ammonium recovered in lysimeters followed a pattern similar to NO_3-N (Table 5). At 39 DAP, 54.67 and 118 mg L^{-1} NH_4-N were present in the soil solution with AN (146 and 225 kg ha^{-1} N, respectively). At 53 DAP, lysimeters in plots with TRT-3 (AN, 225 kg ha^{-1} N) had NH_4-N concentrations statistically higher than an average of all other treatments (25 mg L^{-1}). After 53 DAP, there were no significant differences between treatments. There were no significant differences for either NH_4-N or NO_3-N in lysimeters with CRF treatments for either rate within products or between products at any point during the season.

Table 5
Concentration of soil water NH_4-N (mg L^{-1}) in lysimeters 30 cm below potato bed under AN and CRF treatments in Hastings FL, in 2002

Treatment	N (kg ha^{-1})	Days after planting 39	53	67	81	95
		NH_4-N (mg L^{-1})				
TRT-1	0	2.3 c	0.5 bc	0.3	0.8	0.9
TRT-2	146	54.7 b	6.8 bc	1.0	0.8	0.5
TRT-3	225	117.6 a	25.1 a	6.8	1.5	0.7
TRT-4	146	2.7 c	1.2 bc	0.2	0.3	0.0
TRT-5	225	7.4 c	0.9 bc	0.3	0.5	0.3
TRT-6	146	7.2 c	1.9 bc	0.2	0.3	0.1
TRT-7	225	7.8 c	7.4 bc	0.7	0.6	0.5
TRT-8	146	21.1 c	5.1 bc	1.3	0.8	0.6
TRT-9	225	7.5 c	1.3 bc	2.1	1.8	1.0
TRT-10	146	1.8 c	0.3 c	1.1	0.3	0.3
TRT-11	225	11.1 c	5.3 bc	2.6	1.3	0.7
TRT-12	146	3.0 c	1.3 bc	1.1	1.0	0.6
TRT-13	225	4.9 c	1.6 bc	1.1	2.3	0.8
TRT-14	146	6.4 c	2.8 bc	0.9	1.1	0.2
TRT-15	225	2.0 c	0.9 bc	0.2	0.3	0.2
TRT-16	146	10.8 c	10.5 a–c	1.3	1.2	0.8
TRT-17	225	21.7 c	15.4 a–c	8.1	3.4	2.9
TRT-18	146	12.6 c	8.4 bc	1.6	1.0	0.8
TRT-19	225	10.7 c	3.6 bc	0.7	0.4	0.3
TRT-20	146	9.3 c	14.1 a–c	1.4	1.9	2.5
TRT-21	225	15.0 c	3.4 bc	1.2	1.4	0.6
LSD[1]		28.2	15.0	ns	ns	ns
p-value		<0.01	0.02	0.11	0.78	0.73

[1]Means separated within columns with Fisher's protected least significant difference mean separation test at $p \leq 0.05$.

No significant difference in NO_3-N concentration was found between treatments for any of the sampling dates in the perched water table samples. This may be due to a high dilution of nutrients in the large perched water table below the plots. Wells were not installed 34 DAP. This was too late to monitor the leaching potential from the two early-season rain events. Over the course of the season, a gradual decline in NO_3-N concentration was observed, falling from an average of 16.06 mg L^{-1} at 32 DAP to 5.42 mg L^{-1} at 88 DAP (data not shown).

CONCLUSIONS

The purpose of this research was to investigate a CRF program for potato production under Florida production conditions. This is a continuation of work already reported by Hutchinson et al. in 2003. The "off the shelf" products reported in earlier work (Hutchinson et al., 2003) were replaced in this study with CRFs engineered to release at a rate that approximates the uptake need of potato. In addition, the complete N-P-K CRFs were replaced with CRFs consisting of only urea to reduce cost and improve fertilizer program flexibility. In this study, the 146 kg ha^{-1} N rate resulted in yields and SG comparable to those at the 224 kg ha^{-1} rate. Of the CRF products evaluated, CRF4 and CRF7 resulted in highest yields and merit further testing.

Further improvements in CRF formulation need to occur before a product can be released commercially. However, even at this early stage of development, fertilizer rates can be reduced with a CRF compared with a conventional AN program without reducing tuber yield or quality. In addition, negative impacts on the environment associated with soluble-fertilizer programs may be reduced with a CRF program by potentially reducing N leaching into the watershed. A potato program involving CRFs has the potential to maintain or improve environmental quality, agricultural sustainability, and quality potato production to the benefit of all with interest in agriculture.

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