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Evaluation of Alternative Fertilizer Programs in Seepage Irrigated Potato Production

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The influence of controlled release fertilizer programs and application timing on 'Atlantic' (*Solanum tuberosum* L.) production, tuber quality, and water quality were evaluated. Treatments were arranged in a randomized complete block with four replications. Application timing was at fumigation (21 days prior to planting), planting, at hilling (30 days after planting), and a combination of timings. Fertilizer treatments were no N, ammonium nitrate (N at 224 and 280 kg·ha^{-1}), polymer sulfur coated urea, polymer coated urea, and three liquid urea formaldehyde formulations. Controlled release fertilizer N rate was 196 kg·ha^{-1}. Plants fertilized with the ammonium nitrate (N at 224 kg·ha^{-1}) treatment produced the highest total and marketable yield (39.3 and 34.1 MT·ha^{-1}) significantly higher than with the urea formaldehyde treatments. Total and marketable yields from plants fertilized with polymer sulfur coated urea and polymer coated urea treatments were similar to the ammonium nitrate treatments when the majority of N fertilizer was applied at or before planting. No significant difference was found between fertilizer treatments for tuber quality. The 2007 season was relatively dry with limited N leaching pressure, resulting in few observed differences between treatments for nitrate concentration in the root zone or perched water table over the season.

St. Johns, Putnam, and Flagler counties comprise the Tri-County Agricultural Area in northeastern Florida. The Tri-County Agricultural Area supports approximately 12,400 ha of irrigated agricultural production with potato, cabbage, and sod as predominant crops. The Tri-County Agricultural Area accounts for 65% of statewide potato production. "Best Management Practices" have been implemented for potato production in the Tri-County Agricultural Area to reduce the potential for nitrate movement out of production areas. Seepage irrigation is used in the Tri-County Agricultural Area to maintain a perched water table during production (Hutchinson et al., 2002). Controlled release fertilizers are one component of local Best Management Practices that, through use, may reduce nutrient leaching into the watershed.

Controlled release fertilizers are formulated to provide nutrients to plants at specific times and quantities synchronized with plant demand. Polymer-coated ureas, a type of controlled release fertilizer, release N primarily as a response to soil temperature and not soil moisture. Polymer sulfur-coated ureas are another controlled release fertilizer type similar to polymer coated urea. They consist of a sulfur-coated urea prill encapsulated by a polymer coating. Polymer sulfur-coated ureas can be less expensive to produce than a traditional polymer coated urea but offer more control over nutrient release than a traditional sulfur-coated urea. A third type of controlled release fertilizer is a solution of methylene urea polymers. Unlike polymer coated urea and polymer sulfur-coated urea, the release of nutrients from methylene urea is dependent primarily on microbial activity and is less predictive (Shoji, 1999).

The objectives of this research were to evaluate the influence of controlled release fertilizer programs and application timing on 'Atlantic' tuber production and quality, N removal by the crop, and nitrate (NO_3-N) and ammonium (NH_4-N) leaching.

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Materials and Methods

The experiment was conducted at the University of Florida's Partnership for Water, Agriculture, and Community Sustainability at Hastings Farm in 2007. Soil was Ellzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf; sand 90% to 95%, <2.5% clay, <5% silt). Seepage irrigation was used with a perched water table maintained 45–60 cm below the top of the potato row during the season.

Treatments were arranged in a randomized complete-block design with four replications. Plots were four rows wide (100 cm between rows) by 6.1 m long. Seed spacing within-row was 20 cm. Certified 'Atlantic' seed potatoes were cut into seed pieces (approximately 71 g) and dusted with fungicide (1.1 g a.i. fludixonil and 21.8 g a.i. mancozeb per 45.4-kg seed piece; Maxim MZ, Syngenta Crop Protection, Inc., Greensboro, NC) prior to planting. Potato seed pieces were planted and harvested on 5 Mar. and 11 June 2007, respectively.

Fertilizer treatments were the combination of fertilizer source (Table 1) and application timing (Table 2). Fertilizer treatments were no N, ammonium nitrate, polymer sulfur-coated urea, polymer coated urea, and three liquid urea formaldehyde formulations. Application timing was at fumigation (21 d prior to planting), planting, hilling (30 d after planting), and a combination of timings. Controlled release fertilizer N rate was 196 kg·ha^{-1}. Ammonium nitrate treatments were two split applications with N rate at 224 and 280 kg·ha^{-1} N. All plots received P at 34 kg·ha^{-1} and K at 196 kg·ha^{-1} prior to planting.

A suction lysimeter and polyvinyl chloride pipe casing (10-cm diameter) were installed in each plot at depths of 30 and 100 cm below the top of the potato row, respectively. A vacuum was applied to lysimeters 24 h before each sampling date. Water samples were taken from both lysimeters and wells every 2 weeks during the growing season. Water samples were stored at –5 °C until analyzed for NO_3-N and NH_4-N concentrations using EPA 353.2 and 353.1 methods, respectively (Mylavarapu and Kennelly, 2002).

Table 1. Fertilizer formulation, manufacturer, nitrogen form, and water solubility.

Type	Formulation	Manufacturer	N form	Characteristics
1	34–0–0	Gator Fertilizer	Ammonium nitrate	Water soluble
2	44–0–0	Agrium Fertilizers	Polymer coated urea	Water insoluble
3	38–0–0	Scotts Chemical Co.	Polymer sulfur coated urea	Water insoluble
4	30–0–0	Georgia-Pacific	Urea formaldehyde	Water soluble
5	30–0–0	Georgia-Pacific	Urea formaldehyde	Water soluble
6	28–0–0	Helena Chemical Co.	Urea formaldehyde	Water soluble

Table 2. Fertilizer treatments for 'Atlantic' potatoes grown under traditional and alternative fertilizer programs at the Florida Partnership for Water Agricultural and Community Sustainability farm in Hastings, FL in 2007.

Fertilizer		N rate	Nitrogen rate and application timing (kg·ha^{-1})		
program	Fertilizer[z]	(kg·ha^{-1})	21 DBP[y]	Planting	30 DAP[x]
TRT-1	No N	0	0	0	0
TRT-2	PSCU	196	0	196	0
TRT-3	PSCU+AN	196	0	137 (PSCU)	59 (AN)
TRT-4	PSCU+AN	196	96 (PSCU)	41 (PSCU)	59 (AN)
TRT-5	PCU	196	0	196	0
TRT-6	PCU+AN	196	0	137 (PSCU)	59 (AN)
TRT-7	PCU+AN	196	96 (PSCU)	41 (PSCU)	59 (AN)
TRT-8	UF1	196	0	59	137
TRT-9	UF2	196	0	59	137
TRT-10	UF3	196	0	59	137
TRT-11	AN	224	0	112	112
TRT-12	AN	280	0	140	140

[z]AN, PSCU, PCU, and UF represent ammonium nitrate, polymer sulfur-coated urea, polymer coated urea, and urea formaldehyde, respectively.
[y]DBP is days before planting, which is fumigation timing.
[x]DAP is days after planting, which is hilling timing.

The center two rows of each plot were mechanically harvested. Potato tubers were washed and graded into six size classes using a commercial grading machine according to USDA grading standards (USDA, 1991). Specific gravity was determined using the weight in air/weight in water method (Edgar, 1951).

Pesticide applications during the season were made according to the UF extension recommendations (Hochmuth et al., 2002). Weather data was collected and recorded with the Florida Agricultural Weather Network weather station located on the research farm.

All data were subjected to analysis of variance using SAS ANOVA to evaluate main and interaction effects (SAS Institute, 2004). Fisher's protected LSD test at $P = 0.05$ was used to separate means when appropriate.

Results and Discussion

The fertilizer treatment significantly influenced 'Atlantic' tuber marketable yield, total yield, and tuber quality (Table 3). Plants with the no N treatment (TRT-1) produced the lowest total and marketable yields at 15.7 and 11.5 MT·ha^{-1}, respectively. Plants fertilized with ammonium nitrate (224 kg·ha^{-1} N) treatment (TRT-11) produced the highest total and marketable tuber yield among fertilized treatments (39.3 and 34.1 MT·ha^{-1}) significantly higher than the urea formaldehyde treatments. Potato tuber total and marketable yield from plants treated with the polymer sulfur-coated urea and polymer coated urea treatments were similar to ammonium nitrate treatments when the majority of N fertilizer was applied at or before planting. Thus, at the reduced N rate (196 kg·ha^{-1}), plants treated with polymer sulfur-coated urea and polymer coated urea produced comparable marketable and total tuber yields to ammonium nitrate at 224 kg·ha^{-1} (Best Management Practice rate). The plants fertilized with three liquid urea formaldehydes had lowest yields compared to other fertilized treatments. There were significant differences for total and marketable tuber yields between the different polymer sulfur-coated urea programs (TRT-2, 3, 4) or polymer coated urea programs (TRT-5, 6, 7). This might be attributable to relatively little N uptake by potato at early growth stages.

Polymer sulfur-coated ureas and polymer coated ureas with one time application (TRT 2 and 5) released N at a rate synchronized with plant demand. Fertilizer combinations (TRT-3, 4 and TRT-6, 7) with 30% soluble N applied after planting supplied sufficient N for early potato growth compared to fertilizer programs in which 100% of N was applied at planting (TRT-2 and TRT-5). Controlled release fertilizer programs with N application split at fumigation, planting, and/or hilling are successful alternatives to all controlled release fertilizers applied at planting. Controlled release fertilizers would provide more flexibility in application timing.

There was no significant difference between fertilizer treatments in the "percent tuber weight" in each size class. There was no significant difference in tuber internal or external quality for plants in fertilized treatments (Table 4). Plants in the No-N treatment (TRT-1) produced a significantly higher percentage of rotten tubers relative to other treatments. Specific gravity was similar in tubers in the fertilized treatments (average of 1.083).

Nitrogen recovery values were expressed as a percentage of recovery of applied N. N recovery efficiency was significantly different between treatments (Table 5). Plants treated with granular controlled release fertilizer programs had higher N recovery

Table 3. Total and marketable yields, size distribution, size class range, and specific gravity of 'Atlantic' potatoes produced under traditional and alternative fertilizer programs at the Florida Partnership for Water Agricultural and Community Sustainability (PWACS) farm in Hastings, FL in 2007.

	Yield (T/ha)		Size distribution by class (%)[z]						Size class range (%)		Specific
Treatment	Total	Marketable	C	B	A1	A2	A3	A4	A13	A23	gravity
TRT-1	16.6 d[y]	11.5 d	1.80 a	17.3 a	71.1 a	6.2 d	4.2 b	0	81.4 b	10.3 b	1.077 b
TRT-2	36.0 ab	31.0 ab	1.30 ab	7.9 b	65.6 ab	18.5 bc	7.1 ab	0	91.2 a	25.6 a	1.082 ab
TRT-3	38.1 a	32.3 a	1.22 bc	10.1 b	59.1 bc	22.1 b	7.9 ab	0	89.1 a	30.0 a	1.085 a
TRT-4	33.6 b	27.9 b	1.07 bc	10.8 b	60.3 b	19.9 bc	8.2 ab	0	88.4 a	28.1 a	1.083 a
TRT-5	33.4 b	27.6 b	1.13 bc	9.2 b	65.5 ab	17.3 bc	7.3 ab	0	90.0 a	24.5 a	1.082 ab
TRT-6	33.1 b	27.2 b	1.38 ab	10.0 b	66.8 ab	14.2 c	8.1 ab	0	89.1 a	22.3 a	1.082 ab
TRT-7	35.7 ab	30.3 a	1.00 bc	9.9 b	59.9 bc	22.0 b	7.5 ab	0	89.4 a	29.5 a	1.083 a
TRT-8	31.1 b	26.9 b	0.93 bc	8.6 b	54.4 c	28.9 a	7.7 ab	0	91.0 a	36.5 a	1.083 a
TRT-9	27.4 c	23.5 c	1.08 bc	10.2 b	59.0 bc	20.6 b	10.1 a	0	89.2 a	30.2 a	1.086 a
TRT-10	26.4 c	23.1 c	0.73 c	9.9 b	63.3 ab	19.6 bc	6.6 ab	0	89.5 a	26.2 a	1.085 a
TRT-11	39.1 a	34.0 a	1.22 bc	8.4 b	62.1 bc	21.0 b	7.6 ab	0	90.7 a	28.6 a	1.084 a
TRT-12	37.6 ab	32.6 ab	1.18 bc	8.9 b	61.3 bc	21.2 b	7.6 ab	0	90.3 a	28.7 a	1.083 a

[z]Size classes (cm): C = <3.8cm; B = 3.8–4.8 cm; A1 = 4.8–6.4 cm; A2 = 6.4–8.3cm; A3 = 8.3–10.2cm; A4 = >10.2 cm.
[y]Treatment means followed by the same letter within columns are not significantly different at the $P \leq 0.05$ level using Tukey's studentized range test.

Table 4. Tuber external and internal defects of 'Atlantic' potatoes produced under traditional and alternative fertilizer programs at the Florida Partnership for Water Agricultural and Community Sustainability (PWACS) farm in Hastings, FL in 2007.

	External tuber defects (%)[y]					Internal tuber defects[z] (%)						
										Brown center		
Treatment	GC	MS	SB	Rot	TC	HH	BR	CRS	IHN	L	M	H
TRT-1	0	0.3	9	9.3 a[x]	0	0	0	0 b	0.6	0	0	0
TRT-2	0.8	0	1.3	3.5 bc	5.5	0	0	0 b	0	0	0	0
TRT-3	0.3	0.3	1.8	2 bc	4.3	0	0	0 b	0	0	0	0
TRT-4	0.3	0	1.8	4.8 b	6.8	0	0	0 b	0	0	0	0
TRT-5	0	0.3	3.5	4.3 bc	8.0	0	0	0 b	0	0	0	0
TRT-6	0.3	0	2.3	4.8 b	7.3	0	0	0 b	0	0	0	0
TRT-7	0.3	0	1.0	3.8 bc	5.0	0.6	0	6.3 a	0.6	1.9	0	0
TRT-8	0	0	2.8	2.3 bc	5.0	0	0	0 b	1	0	0	0
TRT-9	0	0.5	1.0	2.5 bc	4.0	0	0	1.8 b	0	0	0	0
TRT-10	0.3	0.8	1.0	1.0 c	3.0	0	0	0 b	1	0.6	0	0
TRT-11	0	0	1.8	2.8 bc	4.5	0	0	0 b	0	0	0	0
TRT-12	0	0.3	1.5	2.5 c	4.3	0	0	0 b	0	0	0	0

[z]HH = hollow heart; BR = brown rot; CRS = corky ringspot;IHN= internal heat necrosis. Brown center: (L)ow, (M)edium, (H)igh.
[y]GC = growth cracks; MS = misshaped; SB = sunburned; Rot = rotten/misc.; TC = total culls. Categories may not appear additive due to rounding.
[x]Treatment means followed by the same letter within columns are not significantly different at the $P \leq 0.05$ level using Tukey's studentized range test.

efficiency than plants in the grower standard program at 280 kg·ha^{-1} N (TRT-12). This indicated that N release from granular controlled release fertilizers at lower N rate (196 kg·ha^{-1}) provided sufficient N for potato growth during the season. The ammonium nitrate treatment (280 kg·ha^{-1} N) provided excess N than plant demand. The excess N might have been loss to under leaching conditions or surface water runoff. Plants treated with the liquid urea formaldehyde treatments had relatively lower N recovery efficiency than plants in ammonium nitrate at 224 kg·ha^{-1} N (Table 5). The lower N recovery efficiency can be attributed to the insufficient N release from liquid urea formaldehyde relative to potato N demand during season.

There was no significant difference between fertilizer treatments for NH_4^+ or NO_3^- concentration in the root zone or perched water table over the season (data not shown). Rainfall totals for March, April, and May were 4.6, 3.1, and 3.2 cm, respectively. Rainfall totals of 7.6 cm in 3 d, or 10 cm in 7 d on coarse-textured soils are considered "leaching rains" in Florida agriculture (Olson and Maynard, 2003). In 2007, there was one leaching rainfall on 16 Mar. (3.2 cm). Overall, the 2007 growing season was relatively dry with limited leaching rainfall events, resulting in few observed differences in water table nutrient concentration between treatments.

In conclusion, plants treated with polymer sulfur-coated urea and polymer coated urea programs when the majority of N was applied at or before planting produced similar total and marketable yields compared to standard soluble fertilizer programs while maintaining water quality. Plants fertilized with liquid urea formaldehyde programs did not produce similar total yield and marketable yield compared to standard soluble fertilizer programs. Polymer sulfur-coated urea and polymer coated urea treatments when the majority of N fertilizer was applied at or before planting had significantly higher N recovery efficiency than ammonium nitrate at 280 kg·ha^{-1} N. The plants treated with the liquid urea formaldehyde treatment had relatively lower N

Table 5. Nitrogen recovery efficiency (NRE) 'Atlantic' potatoes grown under traditional and alternative fertilizer programs at the Florida Partnership for Water Agricultural and Community Sustainability farm in Hastings, FL in 2007.

Fertilizer program	Fertilizer[z]	N rate ($kg\cdot ha^{-1}$)	Nitrogen rate and application timing ($kg\cdot ha^{-1}$) 21 DBP[y]	Planting	30 DAP[x]	NRE[w] (%)
TRT-1	No N	0	0	0	0	---
TRT-2	PSCU	196	0	196	0	40.9 ab[v]
TRT-3	PSCU+AN	196	0	137 (PSCU)	59 (AN)	43.9 a
TRT-4	PSCU+AN	196	96 (PSCU)	41 (PSCU)	59 (AN)	29.6 bc
TRT-5	PCU	196	0	196	0	33.7 abc
TRT-6	PCU+AN	196	0	137 (PSCU)	59 (AN)	28.0 bc
TRT-7	PCU+AN	196	96 (PSCU)	41 (PSCU)	59 (AN)	39.8 ab
TRT-8	UF1	196	0	59	137	31.2 abc
TRT-9	UF2	196	0	59	137	29.5 bc
TRT-10	UF3	196	0	59	137	24.1 c
TRT-11	AN	224	0	112	112	35.3 abc
TRT-12	AN	280	0	140	140	22.8 c

[z]AN, PSCU, PCU, and UF represent ammonium nitrate, polymer sulfur-coated urea, polymer coated urea, and urea formaldehyde, respectively.
[y]DBP is days before planting, which is fumigation timing.
[x]DAP is days after planting, which is hilling timing.
[w]The N recovery efficiency (NRE) will be calculated after harvest for each N program used the method by Zvomuya et al. (2003) by the equation: $NRE = 100 \times (N_{treat} - N_{control})/N_{applied}$.
[v]Treatment means followed by the same letter within columns are not significantly different at the $P \leq 0.05$ level using Tukey's studentized range test.

recovery efficiency than plants treated ammonium nitrate at 220 $kg\cdot ha^{-1}$ N. Overall, some controlled release fertilizers provide a viable alternative to conventional fertilizer sources based on yield and water quality.

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