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Characterization of In-row Movement of Nitrogen during a Rain Event and Its Impact on Northeastern Florida Potato Production

Zhiwei Chen*, Chad M. Hutchinson, and Daniel J. Cantliffe

University of Florida, IFAS, Horticultural Sciences Department, P.O. Box 728, Hastings, FL 32145

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Potatoes (*Solanum tuberosum* L.) in northeastern Florida are produced on sandy soil with low water holding capacity. The objectives of this study were to evaluate the influence of controlled release fertilizer source (N at 196 kg·ha^{-1}) on in-row N movement and to assess the impact of leaching events on 'Atlantic' potato production and tuber quality. Drainage lysimeters were installed at a 45-cm depth from the top of the row for leachate collection. The natural and simulate leaching rain events (5 cm in 2 days and in 2 hours, respectively) were applied at 20–25 cm and full-flower potato growth stages, respectively. Polymer sulfur-coated urea (PSCU) treated plants produced the significantly highest total yields (23.9 ton·ha^{-1}). PSCU and polymer coated urea (PCU) treated plants produced similar marketable yields (18.9 and 17.2 ton·ha^{-1}, respectively) compared to plants in AN treatments (16.4 ton·ha^{-1}). Urea formaldehyde (UF) 1 and 2 treated plants produced significantly lower total (17.5 and 17.8 T·ha^{-1}) and marketable (13.7 and 14.0 T·ha^{-1}, respectively) tuber yields than PSCU treated plants. The plots treated with PCU, UF1, and UF2 had significantly lower NO_3-N concentrations moving downward than the AN in early season.

The tri-county agricultural area (TCAA), consisting of Flagler, Putnam, and St. Johns counties, contains approximately 11,200 ha of irrigated crop land, with the major crops being potato, cabbage, and sod. Soils in the northeastern Florida potato production area are generally sandy with low water-holding capacity, resulting in the potential for nutrient leaching. The excess rainfall events occurring in Florida frequently in the early season increase the potential for the movement of water-soluble nutrients. The nutrient loss not only affects potato tuber yields and quality, but also damages the water quality with the nutrients into watersheds. Therefore, the excess rainfalls give an intensive force to leaching the nutrients down from the nutrient rich soils into the water table. The shallow roots of potatoes have poor holding capacity of the nutrients. The nutrients run into the water table might potentially run out of agricultural system to cause potential pollution.

IFAS recommendations have broadly stated that rainfall of 7.5 cm in 3 d, or 10 cm in 7 d on coarse-textured soils caused nutrient leaching (Olson and Maynard, 2003). However, N leaching depends upon the soil type in a particular area and rainfall intensity. Different soil textures have different capacities to moderate nitrate leaching or run-off. In addition, the percent coverage by the plant canopy also changes water/soil/leaching dynamics. During the potato growing season, evaporate-transpiration (ET) and ground coverage increase until plant full flowering when the maximal plant canopy is produced. A full plant canopy reduces N run-off from the field by reducing the impact of the rainfall. Therefore, a leaching rain may be classified differently depending on the growth stage of the plant.

*Corresponding author; email: zhiwei77@ufl.edu; phone: (904) 692-1792

In this study, the N load into water table was determined under the leaching events at two critical potato growth stages, and the influence of leaching events on potato tuber yields, quality and water quality in northeastern Florida potato production was evaluated. Likewise, in this study, the influence of controlled release fertilizer programs was evaluated in reducing the vertical N loss by leaching into water table under intense leaching events.

Materials and Methods

The experiment was conducted at the University of Florida's Partnership for Water, Agriculture, and Community Sustainability at the Hastings farm in 2008. The soil type was an Ellzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf; sand 90-95%, <2.5% clay, <5% silt). The potato 'Atlantic' was planted with a seepage irrigation maintaining perched water table 45–60 cm below the top of the potato row during the season. Weather data were continuously recorded for the growth season through the Florida Automated Weather Network (FAWN, 2008).

The experiment plots were arranged in a randomized completed-block design with four replications. Plots were four rows wide (100 cm between rows) by 6.1 m long. Potato seed pieces were spaced 20 cm within-row. Potato seed pieces were planted and tubers were harvested on 27 Feb. and 9 June 2008, respectively.

The main treatments were five fertilizer programs (AN and four controlled release fertilizers each applied at Best Management Practice rates; N at196 and 224 kg·ha^{-1} applied at planting, respectively) with a no N control. The five *c*ontrolled release fertilizer were polymer sulfur coated urea (PSCU 38–0–0), polymer coated urea (PCU 44–0–0), two liquid urea formaldehyde products (UF1 30–0–0), and (UF2 28–0–0). All plots also received 15 kg·ha^{-1} P and 163 kg·ha^{-1} K at planting. The natural and simulated leaching events (5 cm in 2 d or 2 h, respectively) were applied at the 20–25 cm and at the full-flower growth stages in each plot. All the data were collected only from the two central rows.

Soil samples were collected before and after irrigation from each plot. Soil was analyzed for NO_3-N, NH_4-N, total Kjeldahl N, P, and K at the University of Florida's Analytical Research Laboratory (ARL) using standard protocol ((Mylavarapu and Kennelly, 2002). Soil moisture was measured at 10, 20, 30, 40, 60, and 100 cm below the soil surface with a soil moisture probe (Dynamax PR2/6 profile) before and after irrigation application. A drainage lysimeter (Fig 1a; composed of a PVC cup with radius 15.4 cm, a drainage plate, and a 255-μm nylon screen) was installed in each plot at a 45-cm depth from the top of the row for leachate collection. Water samples collected from the drainage lysimeters were quantified, filtered, acidified, and frozen until they were analyzed at the ARL for nitrate NO_3-N, NH_4-N, total Kjehldahl nitrogen (TKN), P, and K concentration using standard protocol (Mylavarapu and Kennelly, 2002). The nutrient loads were calculated by the formula:

Nutrient loads = (nutrient concentration × leaching volume)/ lysimeter surface area and the loads were converted into the per hectare basis.

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).

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 program had significant influence on 'Atlantic' tuber total and marketable yields with the leaching events during the growth season. The tuber total and marketable yields of the treatments are shown in Table 1. Under the leaching events, plants with all treatments produced generally lower total and marketable tuber yields than 23.5 $T·ha^{-1}$ and 19.0 $T·ha^{-1}$, respectively. The plants treated with no-N control produced the lowest total yield and marketable yield (6.9 and 4.8 $T·ha^{-1}$, respectively) with the lowest tuber specific gravity at 1.070. The plants treated with PSCU treatment produced the significantly highest total tuber yields (23.9 $T·ha^{-1}$). The plants under PSCU and PCU treatment produced similar marketable yields at lower N rate (N at 196 $kg·ha^{-1}$) compared to plants treated with AN at 224 $kg·ha^{-1}$ N. Therefore, the percentage of size A2 to A3 (6.4–10.2 cm) were significantly highest for plants treated with PSCU and PCU programs. The plants treated with liquid UFs had significantly lower total and marketable yields (17.5 and 17.8 $T·ha^{-1}$; 13.7 and 14.0 $T·ha^{-1}$, respectively), which might be attributed to too slow release characteristic of these two fertilizers without releasing sufficient N to synchronize the N demand of 'Atlantic' potato at early growth stage. The microbial activity in Florida sandy soils of potato production was generally low, limiting the release of the aqueous UF products because the N release of UF products is strongly dependent on the soil microbial activity. The tuber specific gravity (SG) of tubers from plants treated with PSCU,

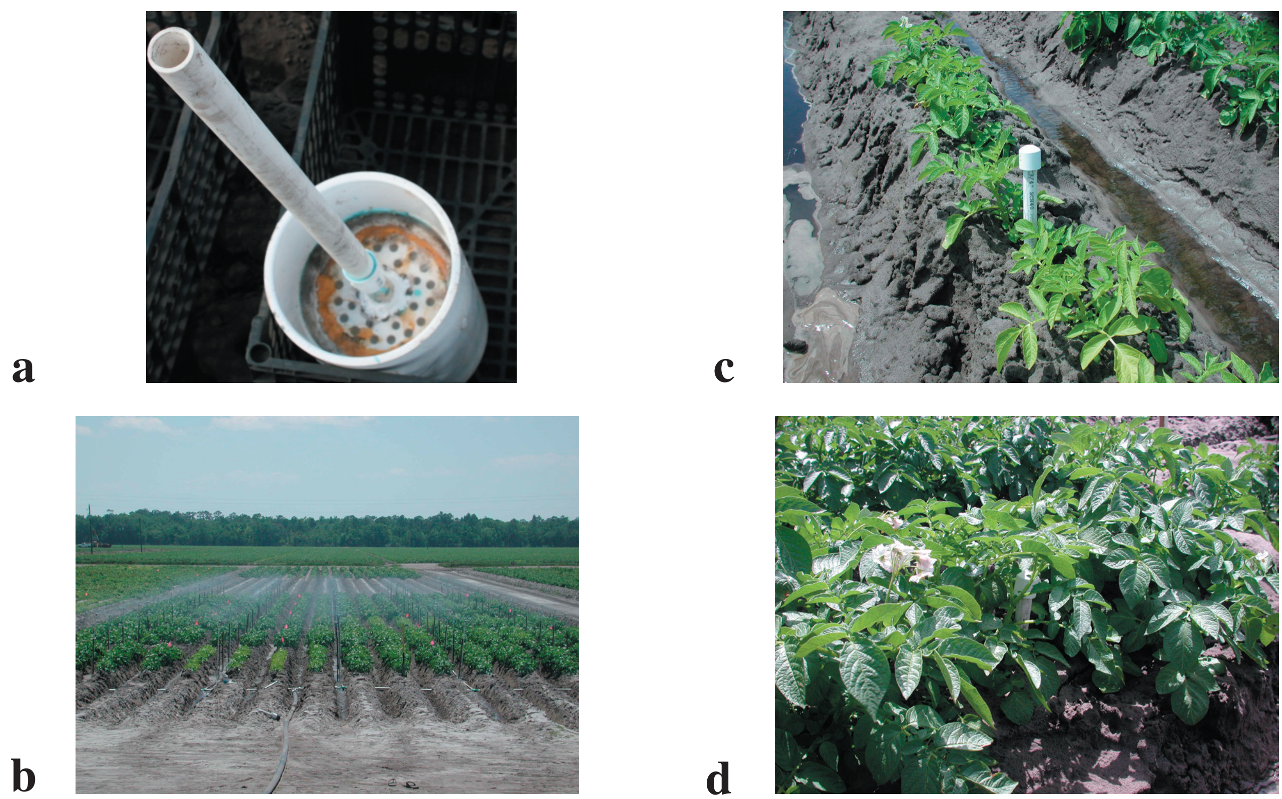

Fig 1. (**a**) The drainage lysimeter (composed of a 15-cm cup, a drainage plate, and a 255-μm nylon screen). (**b**) Simulated irrigation as potential leaching event at full-flower stage. (**c**) The drainage lysimeter in a plot with no-N control. (**d**) A drainage lysimeter in a plot with PSCU.

Table 1. Production statistics for 'Atlantic' potato grown with differing fertilizer treatments and under a simulated leaching event at the UF/IFAS PWACS Demonstration Farm in Hastings, FL in 2008.

	Total yield	Marketable yield[y]	Size distribution by class (%)[x]						Size class range (%)		
TRT[z]	($T \cdot ha^{-1}$)	($T \cdot ha^{-1}$)	C	B	A1	A2	A3	A4	A1 to A3	A2 to A3	SG
No N	6.9 d	4.8 c	4 a	26 a	68	1 c	0 d	0	69 b	1 c	1.070 c
PSCU	23.2 a	18.9 a	1 c	7 b	63	16 a	13 ab	0	92 a	28 a	1.084 a
PCU	21.2 ab	17.2 a	2 bc	6 b	64	12 ab	17 a	0	92 a	29 a	1.082 a
UF1	17.5 c	13.7 b	2 bc	10 b	65	10 ab	12 a-c	0	88 a	22 ab	1.078 b
UF2	17.8 bc	14.0 b	2 bc	11 b	71	11 ab	5 cd	0	87 a	16 b	1.078 b
AN	19.7 bc	16.4 ab	2 bc	8 b	73	9 b	7 bc	0	90 a	17 b	1.082 a
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.4244*	*0.0011*	*0.0005*	---	*<0.0001*	*<0.0001*	*<0.0001*
LSD[w]	*3.5*	*3.1*	*1*	*6*	NS	*6*	*7*	*0*	*7*	*10*	*0.003*

[z]All treatments receive 196 $kg \cdot ha^{-1}$ during growing season except 'No Nitrogen' and AN (ammonium nitrate: 224 $kg \cdot ha^{-1}$).
[y]Marketable yield: size classes A1 to A3.
[x]Size classes (cm): C = <3.8 cm; B = 3.8–4.8 cm; A1 = 4.8–6.4 cm; A2 = 6.4–8.3 cm; A3 = 8.3 –10.2 cm; A4 = >10.2 cm.
[w]Means separated within columns by least significant difference (LSD) test at $P \leq 0.05$. Means with the same letter are not significantly different (NS).

Table-2. In-row leaching NH_4-N, NO_3-N, and TKN concentration and load into perched water table from differing fertilizer treatments after a natural leaching rainfall at the 20–25 cm potato growth stage at the UF/IFAS PWACS Demonstration Farm in Hasting, FL in 2008.

	Concn ($mg \cdot L^{-1}$)				Nutrient load ($kg \cdot ha^{-1}$)		
TRT[z]	NH_4-N	NO_3-N	TKN	Volume (mL)	NH_4-N	NO_3-N	Total N
No N	3.8 b	2.8 b	8 b	2093.8	3.2	1.9	10.0
PSCU	16.2 a	24.4 a	16.3 a	660.0	6.3	12.4	18.4
PCU	2.6 b	1.6 b	6.1 b	912.5	1.4	0.7	3.6
UF1	7.4 b	1.5 b	10.4 ab	1643.8	4.7	0.2	7.1
UF2	2.6 b	3.5 b	5.5 b	1315.0	2.3	1.2	5.3
AN	3.8 b	27.2 a	5.9 b	1145.0	3.2	8.8	13.3
P-value	*0.007*	*0.040*	*0.026*	*0.495*	*0.487*	*0.127*	*0.282*
LSD[y]	*7.2*	*20.8*	*6.6*	NS	NS	NS	NS

[z]All treatments receive 196 $kg \cdot ha^{-1}$ during growing season except 'No Nitrogen' and AN (ammonium nitrate: 224 $kg \cdot ha^{-1}$).
[y]Means separated within columns by least significant difference (LSD) test at $P \leq 0.05$. Means with the same letter are not significantly different (NS).

PCU and AN programs were above 1.082, which was significantly higher than tubers from plants treated with liquid UFs (1.078). There was no significant difference observed for tuber external and internal quality for tubers between all fertilized program (data not shown).

The collected water sample quality (nutrient content) was significantly affected by the fertilizer program under the leaching events at 20–25 cm stages (Table 2 for N content; the data of P and K leaching not shown). At potato 20–25 cm stage, water samples collected from the plots treated with PSCU and AN had the highest concentration of NO_3-N. The water volume collected from the plots treated with PSCU tended to have the relatively lowest amount but with the significantly highest concentration of NH_4-N and TKN, which was consistent with its high yield performance. A early rainfall (8.1 cm) at 11 d after planting (DAP) might leach downward the soluble NO_3-N in AN treated plots, also resulting in the lower yields for plants treated with AN. The higher concentration of NH_4-N and TKN in PSCU treated plots was also attributed to its fast release. The downward N movement was not significant for all fertilized programs at full-flower stage (Table 3) because of the less available N and more active N uptake by plants at this stage. At both stages, the plots with no-N control tended to have the highest downward water volume because the poor canopy provided little buffer under the potential leaching events. However, at both stages, the N loads (NH_4-N, NO_3-N, total N) were not significantly different among fertilizer programs because the leaching events (5 cm) in this study might have not been intensive enough for a strong leaching force and the early N loss might already existed due to an potential leaching rainfall (8.1 cm) at 11 d after planting (DAP).

The soil analysis results (Fig. 2) indicated that the soil in plots treated with the liquid UFs showed a trend of slight increasing concentration of NH_4^+ even after the leaching event. The slight increase might be attributed to the continuous N release of UF products at full-flower stage. The release of urea from the UFs converted into the NH_4-N with the positive charge before the nitrification. The positive NH_4^+ tended to leach less due to the negative charges associated with the negatively charged soil's cation exchange capacity. However, the concentration of NO_3-N in the soil treated with the liquid UFs decreased significantly higher than other fertilizer programs due to the continuous release and poor canopy. The concentration of NH_4^+ and NO_3^- in soil treated with PSCU and PCU decreased significantly higher than soil treated with AN. The concentration of NO_3^- in soil with No-N control decreased under leaching event because the small plants in no-N control plots had poor roots holding the negative NO_3^- and the poor canopy provided little buffer for water running downward.

The drainage lysimeters can be used to successfully determine the in-row downward N loads (NH_4-N, NO_3-N, total N) into the

Table 3. In-row leaching [NH_4-N], [NO_3-N] and TKN concentration and loads from differing fertilizer treatments after a simulated leaching rainfall at the full-flower potato growth stage at the UF/IFAS PWACS Demonstration Farm in Hasting, FL in 2008.

	Concn ($mg\cdot L^{-1}$)				Nutrient load ($kg\cdot ha^{-1}$)		
TRT[z]	NH_4-N	NO_3-N	TKN	Volume (mL)	NH_4-N	NO_3-N	Total N
No N	3.8 b	2.8 b	8 b	2093.8	3.2	1.9	10.0
No N	2.4	7.6	9.3	1207.5	1.3	4.5	14.0
PSCU	6.8	36.4	12.1	248.8	1.2	10.0	12.3
PCU	4.8	38.3	8.7	402.5	0.8	16.4	8.5
UF1	2.0	25.1	8.4	440.0	0.6	6.9	3.7
UF2	2.2	12.8	10.1	227.5	0.3	2.5	3.7
AN	15.5	80.5	12.5	467.5	8.4	35.6	41.2
P-value	*0.556*	*0.381*	*0.962*	*0.442*	*0.515*	*0.609*	*0.699*
LSD[y]	NS	NS	NS	NS	NS	NS	NS

[z]All treatments receive N at 196 $kg\cdot ha^{-1}$ during growing season except "No N" and AN (N at 224 $kg\cdot ha^{-1}$).
[y]Means separated within columns by least significant difference (LSD) test at $P \leq 0.05$. Means with the same letter are not significantly different (NS).

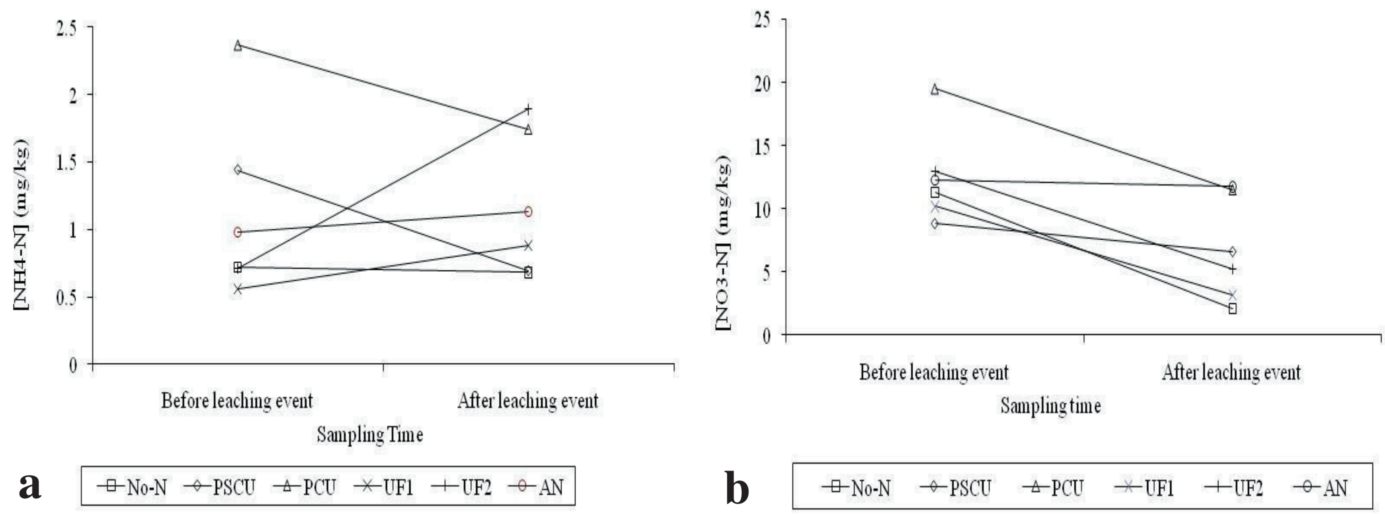

Fig 2. (**a**) The in-row leaching NH_4-N concentrations before and after the leaching events at full-flower stage. (**b**) The in-row leaching NO_3-N concentration before and after the leaching events at full-flower stage.

water table. The N loads were not significantly different at both stages under the 5-cm leaching events in this study because of an early N loss and a relatively weak leaching force. However, the NO_3-N concentration of leaching water samples was higher for water samples from plots treated with AN program than PCU, UFs at early season. At the N rate of 196 $kg\cdot ha^{-1}$, potato plants treated with the PSCU and PCU program produced similar marketable tuber yields compared to AN program under the potential 5-cm leaching rainfall at both two critical growth stages. However, the very slow release controlled release fertilizers with large amount N left after growth season might cause the potential risk of the NO_3-N leaching with the excessive rainfall at the late potato growth season.

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