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Effect of Nitrogen Rate on Yield of Tomato Grown with Seepage Irrigation and Reclaimed Water

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Because reclaimed water may contain up to 9.9 ppm of nitrate-nitrogen, it may be a source of N that should be counted in the fertilization programs of seepage-irrigated tomato (*Solanum lycopersicon* L.). The objective of this study was to assess the contribution of non-fertilizer N sources on tomato grown with seepage irrigation and reclaimed water. The study was conducted in Spring 2006 in Palmetto, FL, with N rates ranging from 20 to 420 lb/acre. Based on a 50% use of N in reclaimed water and organic matter mineralization, an estimated 56 lb/acre of N were supplied by non-fertilizer sources. Sap NO_3-N concentrations were similar and "sufficient" with N rates between 116 and 476 lb/acre throughout the season. Extra-large yield at first harvest (70% of total yield) responded slightly negatively to N rates. Total marketable, total extra-large, total first and second harvest yields, and fruit quality parameters did not respond to N rates. These results with spring-grown tomato harvested twice suggest that 1) the N contribution of the reclaimed water to the crop should be counted in the overall N fertilization program; 2) tomato yields and nutritional status responses to N rates from all sources were small; 3) more than 50% of the N supplied by the reclaimed water was used by the plant; and (4) grower's N rate could be reduced by 50% to 100% of the NO_3-N contribution of the reclaimed water without reducing yield or quality, thereby resulting in a $18 to $37/acre reduction in fertilization cost.

Protecting the quality and quantity of water resources in Florida includes appropriate handling and reuse of wastewater from domestic or industrial wastewater treatment facilities [Florida Department of Environmental Protection (FDEP), 2007). Failure to properly dispose of the millions of gallons of wastewater produced every day may negatively impact Florida's drinking water supply, wildlife, and the environment (FDEP, 2007). Hence, Sections 373.250 and 403.064, Florida Statutes (F.S.) "encourage and promote the reuse of reclaimed water as described in FDEP's comprehensive reuse program" [FDEP, 2007; Chapter 62-610, Florida Administrative Code (FAC)]. Water reuse involves taking domestic or industrial wastewater generated by the approximately 4130 individually permitted wastewater facilities in Florida, adequately treating it to protect public health, and using the resulting high-quality reclaimed water for a new, beneficial purpose (FDEP, 2007). Reclaimed water may be discharged to ground or surface water or may be used for irrigation purposes instead of ground water.

Water quality may also be protected by reducing the risk of off-site fertilizer movement. The optimum fertilization management and application section of the best management practice manual for vegetables (adopted by rule 5M-8, FAC) are based on the recommendations of UF-IFAS under BMP No. 33 [Florida Department of Agriculture and Consumer Services (FDACS), 2006]. To develop environmentally sound fertilization practices, the contribution of reclaimed water to the N fertilization program need to be determined, and the rates of mineral fertilizer may need to be adjusted accordingly. Therefore, the objectives of this study were to 1) assess the contribution of non-fertilizer N sources to the crop; 2) evaluate the effect of N fertilizer rate when reclaimed water was used for seepage-irrigated tomato on plant nutritional status, tomato fruit marketable yield and distribution, and postharvest quality; and 3) consider adjustments in applied fertilizer rate.

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Materials and Methods

A fertilizer trial was conducted in Spring 2006 in a commercial tomato field near Palmetto, FL, on EauGallie fine sand. Soil organic matter content before field preparation was determined by loss on ignition (Dellavalle, 1992) on a composite soil sample collected 10 Jan. 2006. The field was then rototilled, and the pre-plant fertilizer (bottom mix) was applied following the modified broadcast method to supply 20, 79, and 33 lb/acre of N, P, and K, respectively. Beds were 32 inches wide, 8 inches tall, and formed on 6-ft centers (1 acre = 7260 linear bed feet). In this field, an irrigation ditch was present every three beds. Plots consisted of 20-ft-long sections of three adjacent beds. The experimental design was a randomized complete-block design with four replications. On 12 Jan., N rates were applied as ammonium nitrate placed by hand in two grooves formed on the top of the bed (hot bands) using pre-calibrated cups at rates of 0, 40, 100, 160, 220, 280, 340, and 400 lb/acre. Since 20 lb/acre were already present in the bottom mix, total fertilizer-applied N rates were 20, 60, 120, 180, 240, 300, 360, and 420 lb/acre. The potential contribution of the reclaimed water to the N supply was not known at the beginning of the experiment. The remainder of K was applied to the grooves by hand using KCl at a rate of 475 lb/acre of K. Hence, total K rate applied (cold mix + hot mix) was 508 lb/acre. Grower commercial K rate was used in all the N treatments. After fertilizer application, beds were fumigated with methyl bromide and chloropicrin (67:33, w:w) at the rate of 300 lb/acre. The position of the shanks used to inject methyl bromide did not affect the integrity of the groves. All beds were immediately covered with low-density black polyethylene mulch. On 22 Feb., 'Florida 47' tomato transplants (Seminis, Oxnard, CA) were established in the field 24 inches apart, which created a stand of approximately 3630 plants/acre. Tomatoes were then grown following UF/IFAS pesticide recommendations according to the scouting reports (Olson et al., 2006).

The field was seepage irrigated with reclaimed water. Seepage irrigation consists of the management of a water table perched on an impermeable layer and supplies water to the root zone through upward capillary movement. The water table was maintained approximately at the 18-inch depth for the first month of the growing season and at the 24-inch depth thereafter (Simonne et al., 2006). Actual water table depth was measured using shallow water-table monitoring wells placed in each replication (Smajtrala, 1997). Farm water meters were used to determine irrigation volume applied to the field. Nitrate-nitrogen and NH_3-N daily concentrations were determined by the Central Laboratory/Industrial Compliance of Manatee County by EPA ion chromatography method 300 for nitrate (NO_3-N, USEPA, 1993), EPA colorimetric method 350.1 for ammonia (NH_3-N, USEPA, 1983), and total Kjeldahl Nitrogen (TKN) by Colorimetric, Semi-Automated Block Digester, AAII (EPA method 351.2). Daily monitoring reports showing mean concentrations of NO_3-N, NH_3-N, and TKN supplied by Manatee County Utility Operations, Bradenton, FL were used to calculate mean monthly N supplies by the reclaimed water. Monthly N contributions from the reclaimed water were calculated by multiplying N concentrations by volume of irrigation water applied.

Beginning at first flower and continuing until second harvest, fresh petiole sap NO_3-N and K concentrations were measured bi-weekly using ion-specific meters (Cardy, Spectrum Technologies, Inc., Plainfield, IL; Olson et al., 2005; Studstill et al., 2006). Tomatoes were harvested on 24 May and 7 June on nine representative plants (three from each bed). Marketable mature-green and colored tomatoes were graded in the field according to USDA specifications for extra-large (5 × 6), large (6 × 6), and medium (6 × 7) fruit categories (USDA, 1997). Harvested plants were clearly marked and protected with coarse nets to prevent unscheduled harvests by commercial crews.

Postharvest evaluation was done at both harvests on 10 uniform tomatoes at breaker/turning stage sampled from each plot. After harvest, tomatoes were placed in labeled paper bags and transported to the UF Postharvest Horticulture Laboratory in Gainesville, FL. Tomatoes were held overnight at 68 °F, and the four most uniform fruits from each treatment were selected the next day. These fruits were stored at 68 °F until they reached table-ripe stage defined as "the point at which red-ripe tomatoes became noticeably softer when pressure was applied with thumb and fingertips to the equatorial region of each fruit." Soluble solids concentration (SSC), total titratable acidity (TTA), and pH were measured at the table-ripe stage. The frozen pulp samples were thawed and homogenized then centrifuged at 15,000 RPM for 20 min at 41 °F. The supernatant was filtered through cheesecloth, and a 0.013 lb aliquot of filtrate was used to asses SSC (using a Mark Abbe II digital refractometer; Reichert-Jung, Model 10480, Depew, NY), pH (using a Corning 140 pH meter, Medfield, MA), and TTA (by titration with 0.1 N NaOH using a Fisher Model 395, Pittsburgh, PA).

Data yield components, SSC, pH and TTA responses to N rates were analyzed using regression analysis (SAS, 2002).

Results and Discussion

Inventory of non-fertilizer N sources. Using average concentrations of N as NO_3-N, NH_3-N, and TKN in reclaimed water and a daily reclaimed water irrigation rates of 8310 gal/acre/day for a 16 week-long crop (from transplanting to second harvest), it was calculated that 61, 1.3, and 5.4 lb/acre of N as NO_3-N, NH_3-N, and TKN, respectively, were supplied by the reclaimed water during the growing season (Table 1). Assuming a 50% N uptake efficiency by the tomato plants from the reclaimed water, the reclaimed water uniformly supplied an estimated 34 lb/acre of N (0.50 × 68). Organic matter content (OM) in the field was 2.8% which was higher than the typical 1% to 1.5% OM content of most Florida sandy soils. Assuming a 2% mineralization rate throughout the growing season (Kye-Han and Shibu, 2006), it was estimated that OM mineralization contributed 22 lb/acre of N. Hence, the N rate available to the tomato plant from sources other than soluble fertilizer (mineralization + irrigation water) was 56 lb/acre. This amount represents approximately a quarter (28%) of the UF/IFAS recommended rate of 200 lb/acre of N. At the current cost of $0.40 lb of N, this N amount has a soluble

Table 1. Average monthly concentrations of NO_3-N, NH_3-N, and total Kjeldahl nitrogen (TKN) in the reclaimed water between tomato transplanting (22 Feb.) and second harvest (7 June) during spring season 2006.[z]

Month	NO_3-N	NH_3-N	TKN
	----------------------	ppm	-------------------
February	4.00	0.193	1.39
March	9.40	0.173	1.56
April	8.50	0.191	1.54
May	7.63	0.163	1.23

[z]Based on the daily report provided by the Manatee County Treatment Facility.

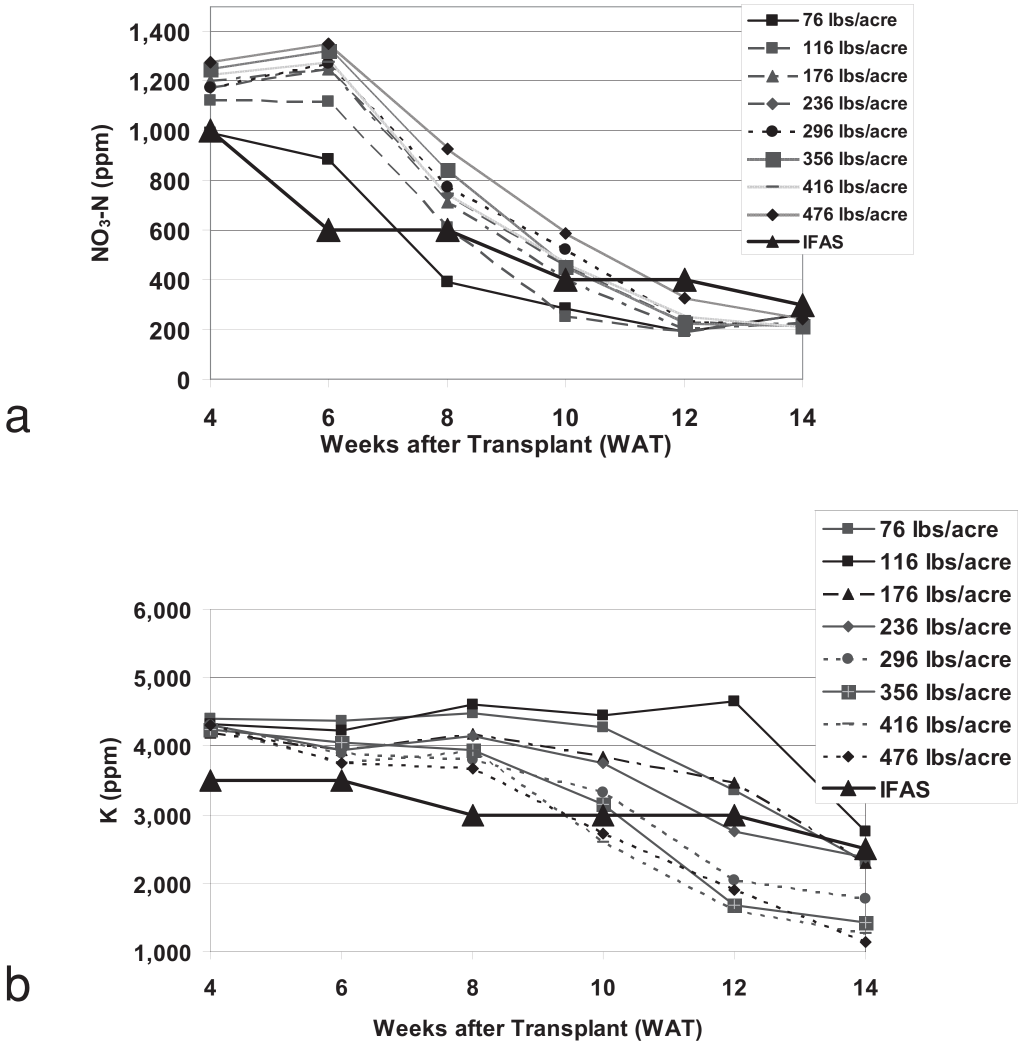

Fig. 1. 'Florida 47' tomato NO_3-N (**a, top**) and K (**b, bottom**) sap petiole concentration response to N rates during Spring 2006. (Rates included contributions from the reclaimed water, organic matter mineralization, and fertilizer application; transplanting date was 22 Feb.).

fertilizer equivalent value of $22/acre. In addition, the N rates used to describe tomato yield response were increased by 56 lb/acre to include all the N sources. Hence, N fertilizer rates used for analyses were 76, 116, 176, 236, 296, 356, 416, and 476 lb·acre^{-1}.

Plant nutritional status. Overall, NO_3-N petiole concentration followed the pattern typically observed with seepage irrigation (Fig. 1a). Nitrate-nitrogen concentrations were above the sufficiency values on 4 and 6 WAT (weeks after transplant), declined thereafter, and fell below the sufficiency value on 12 WAT. The rate of decline depended on the N fertilizer rate. Petiole sap NO_3-N concentrations were significantly lower with the 76 lb/acre rate than with the other N treatments on 4 and 6 WAT. On 8 and 10 WAT, plants receiving the 76 and 116 lb/acre treatments had the significantly lowest NO_3-N concentration and plants receiving the 476 lb/acre treatment had the significantly highest petiole sap NO_3-N than the rest of the N treatments. On 12 WAT, the petiole sap NO_3-N concentration was the highest with the 420 lb/acre rate than with the other rates. Although this study did not involve K treatments, petiole sap K concentrations were affected by N rates beginning 6 WAT (Fig. 1b). On 6, 8, and 10 WAT, the highest petiole sap K concentrations were found with the 76 lb/acre rate, followed by 116, 176, 236, 296, and 356 lb/acre, and the lowest were with 416 and 476 lb/acre. Finally, on 12 and 14 WAT, the highest petiole sap K concentrations were found with the 116 lb/acre rate, followed by the rest of the treatments; the lowest were 356, 416 and 476 lb/acre among N treatments. Petiole sap K concentrations tended to be above the UF-IFAS sufficiency threshold concentrations during the first 10 WAT with all the treatments (Fig. 1b). On 10 WAT, K petiole sap concentrations with all N treatments were above the sufficiency range, except with the lower N treatments (76, 116, and 176 lb/acre treatments). In general, tomatoes with the lowest N rates had the lowest sap NO_3-N contents, but also had the highest petiole K sap contents. These results show that fertilizer rates above 176 lb/acre of N did not improve plant nutritional status and did not prevent the drop in NO_3-N concentration at the end of the season.

Yield response to N rates. Spring 2006 was warm and dry in central Florida. No leaching rainfall occurred and there was no need to raise the water table for frost protection during the growing season. Hence, off-site fertilizer movement was minimal. Tomatoes were harvested twice as typically done with spring plantings in central Florida. Overall, the first harvest accounted

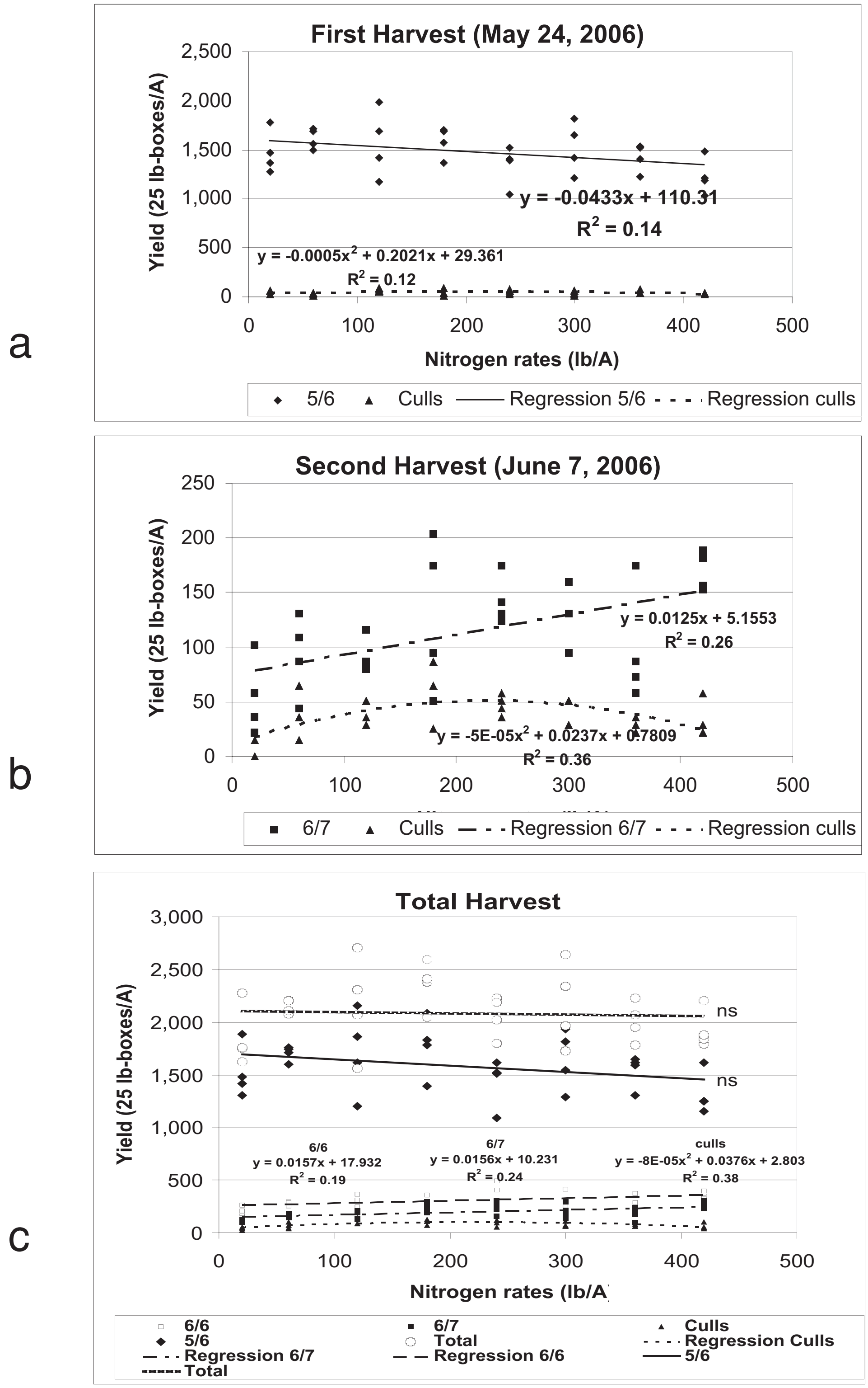

Fig. 2. 'Florida 47' tomato yield response to N rates during Spring 2006 from the first (**a, top**), second (**b, middle**) and both harvests combined (**c, bottom**). (N rates were calculated by adding the contribution of reclaimed water, organic matter mineralization, and soluble fertilizer rate.)

approximately for 90% of the total yield, while the second harvest accounted for only 10%. At the first harvest, large and medium fruit category yield response to N rates was nonsignificant ($P > 0.05$). Extra-large grade yield response to N rates was linear with a negative slope (Fig. 2a). Extra-large fruit yields at first harvest represented approximately 70% of total yield. A slope of –0.0433 means that first-harvest extra-large yields decreased by five 25-lb boxes/acre for each added 100 lbs of N. Cull yields at first harvest were overall small. At the second harvest, extra-large yield response to N rates was nonsignificant. Large yield response to N rates was linear with a slope of +0.0125 (an increase in 100 lbs of N produced a yield increase of 1.2 25-lb box/acre). This category represents approximately 5% of total yield. Based on current N fertilizer prices, it takes approximately a yield increase of ten 25-lbs boxes/acre to offset the cost of 100 lbs of N. In this study, the yield increase in large fruit at the second harvest (slope of +0.0125) representing 5% of the total yield did not offset the yield decrease in extra-large category at the first harvest (slope –0.0433). Similar studies that used reclaimed water on corn (*Zea mays* L.) and forage crops with a furrow irrigation equivalent to 100% and 125% class A pan indicated an increased soil P, K, Fe, Mn contents, and soil OM in the topsoil at the highest rate of reclaimed water (Mohammad and Mazahreh, 2003). These results have two implications. First, under the favorable weather conditions of Spring 2006, tomato did not respond to N rates greater than the UF/IFAS recommended rate when only two harvests were conducted as typically done with spring plantings. Second, the N rates used to assess yield response to N rates were based on the assumption that tomato used 50% of the N supplied by the reclaimed water. Nitrate petiole results on 8 and 10 WAT and yield responses to N rate suggest that tomato may have actually used more than 50%. One of the limitations of the study was to be able to quantify the fraction of N in the reclaimed water used by the tomato plants. But, in this study it was shown that the N supplied by the reclaimed water was a significant source of N for tomato and should be counted in the fertilization program.

Postharvest evaluation. The effect of N rate on tomato pulp pH, TTA, and SCC was nonsignificant at both harvests ($P = 0.17$, 0.32, 0.38 and 0.89, 0.80, 0.95, for harvests 1 and 2, respectively). Ranges of fruit at first harvest for SSC were 4.15–3.23 °Brix, TTA 0.38–0.28 mEq/100 g juice, and pH 4.39–4.32; and SSC 4.8–3.3 °Brix, TTA 0.39–0.28 mEq/100 g juice, and pH 4.4–4.45 for the second harvest. The first harvest means and standard deviation were SSC 3.53/0.29 °Brix, TTA 0.33/0.03 mEq/100 g juice, and pH 4.35/0.03; and SSC 4.23/0.5 °Brix, TTA 0.35/0.04 mEq/100 g juice, and pH 4.4/0.03 for the second harvest. The values obtained for SSC, TTA, and pH are within the range of typical values that have been reported previously for 'Florida-47' tomatoes. Therefore, tomato fruit pH, SSC, and TTA did not respond to N rates from 76 to 476 lb/acre and was acceptable over the entire N range. These results do not support the attempts to improve fruit quality by increasing N rate and suggest that fruit quality was not affected within this broad range of N rates applied.

In conclusion, these results with spring-grown tomato harvested twice suggest that 1) the N contribution (here $N\text{-}NO_3$) of the reclaimed water to the crop should be counted in the overall N fertilization program; 2) tomato yields and nutritional status responses to N rates from all sources were small, suggesting that more than 50% of the N supplied by the reclaimed water was used by the plant; and 3) grower N rate could be reduced by 50% to 100% of the equivalent amount of the contribution of the reclaimed water (34 to 68 lb/acre of N) without affecting yield or quality, thereby resulting in a saving in fertilization cost of $14 to $28/acre (assuming a cost of $0.41/lb of N).

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