Effects of Reclaimed Water Irrigation on Growth and Nitrogen Uptake of Turfgrass

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SUMMARY. Reclaimed water (RW) is increasingly viewed as a valuable resource for supplying irrigation water and nutrients for landscape plants growing in urban environments. A greenhouse experiment was conducted to determine if nitrogen (N) in RW contributes significantly to turfgrass plant nutrition and to measure N use efficiency and the effects of irrigation with RW on N leaching. The factorial experiment was replicated four times and conducted in a greenhouse on the University of Florida campus for 1 year using ‘Floritam’ st. augustinegrass (*Stenotaphrum secundatum*) and ‘Empire’ zoysiagrass (*Zoysia japonica*). Treatments included irrigation with tap water (control), irrigation with RW from University of Florida wastewater treatment facility, irrigation with RW with additional N supplied from ammonium nitrate to achieve 5, 9, and 13 mg·L⁻¹ N solutions, and a dry prilled fertilizer treatment based on the recommended N application rate for turfgrass in northern Florida. The average total N and phosphorus (P) concentrations of RW, based on 1 year weekly monitoring were 3.31 mg·L⁻¹ total N with 2.14 mg·L⁻¹ nitrate-N and 0.46 mg·L⁻¹ ammonium-N, and 2.00 mg·L⁻¹ P composed of 1.92 mg·L⁻¹ orthophosphate. Turfgrass growth responded positively ($P < 0.05$) to N concentration in the irrigation water. The concentration of N in the unamended university campus RW was not sufficient for optimal turfgrass growth. Grass quality and turfgrass clippings yield maximized when the total N concentration in the irrigation water was at least 5 mg·L⁻¹. Turfgrass receiving dry synthetic N fertilizer resulted in greater growth and 2-fold greater N leaching than with the remaining treatments for both turf types. The highest N recovery percentage for both turf types was found when the N concentration in the solution was 5 mg·L⁻¹.

Severe competition for water resources is predicted as the population continues to grow in southern United States (O’Connor et al., 2008; Sun et al., 2008). The continued availability of inexpensive potable water for irrigation is in question. Further, the price of fertilizers has been increasing over the last decade. In 2010, the fertilizer price index in the United States was 5-fold higher than that in 1960 (U.S. Department of Agriculture, 2010). Under this scenario,

the use of reclaimed wastewater is increasingly viewed as a resource for supplying irrigation water and nutrients for landscapes (Harivandi, 2004). Reclaimed water contains nutrients, such as N and P, which are essential plant nutrients. Currently, Florida is a leading user of RW with more than 50% of the state’s RW going to irrigation

of recreational areas, including golf courses, parks, athletic fields, and residential landscapes (Toor and Rainey, 2009).

Most of the studies with RW have focused on the detrimental effects of soluble salts on plant growth and soil quality, groundwater enrichment of N and P, and environmental protection strategies (Kalavrouziotis et al., 2008; Maurer et al., 1995; Pedrero and Alarcon, 2009; Thomas et al., 2006; Wang et al., 2003; Xu et al., 2009, 2010). Pereira et al. (2011, 2012) found plant nutrients and nonessential elements tended to accumulate in the soil after 11 years of RW irrigation. Therefore, seasonal and annual N fertilization amounts should be adjusted when nutrients in the irrigation source may contribute to the nutritional needs of plants (Carrow, 2012). Hayes et al. (1990a,b) demonstrated that the use of wastewater effluent to supply adequate water for bermudagrass (*Cynodon dactylon*) growth in Arizona also resulted in increased concentrations of soil nitrate. King and Balogh (1999) were able to significantly decrease off-site nitrate-N transport, with a resulting improvement in water quality, by reducing the application rates of fertilizers as irrigation rates were increased. In a multi-year irrigation study continuous use of saline irrigation water without flushing of salts by rainfall resulted in accumulation of salts in the soil to a level detrimental to turfgrass health (Evanylo et al., 2010). However, such an effect depends on soil type, grass type, and climate. Sevostianova et al. (2011a,b) documented no negative effects from saline irrigation and salt

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	inch ²	cm ²	0.1550
48.8243	lb/1000 ft ²	kg·ha ⁻¹	0.0205
1.1209	lb/acre	kg·ha ⁻¹	0.8922
1	μmho/cm	μS·cm ⁻¹	1
1	mmho/cm	dS·m ⁻¹	1
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274 × 10 ⁻⁵
7.0053	oz/acre	mg·m ⁻²	0.1427
33.9057	oz/yard ²	g·m ⁻²	0.0295
1	ppb	μg·L ⁻¹	1
0.001	ppm	mg·g ⁻¹	1000
1	ppm	mg·kg ⁻¹	1
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

accumulation for several warm-season grasses. Micronutrients supplied in RW accumulated to excessive concentrations in plants. Micronutrients, such as boron (B) and copper (Cu), supplied in RW tended to be excessive for plants (Pereira et al., 2011) and heavy metals were a concern (Exall et al., 2004).

There are three stages of wastewater treatment: primary, secondary, and advanced. Reclaimed water is wastewater that has received at least secondary treatment. The main difference between RW that has received secondary versus advanced treatment is the reduced level of nutrients and other chemicals remaining in water subjected to advanced treatment. Water receiving advanced treatment typically has 25% of the N and P and less soluble salts than contained in secondary treated RW (Asano et al., 2007). Increasingly, RWs used for irrigation are from advanced wastewater treatment facilities. As the production of RW increases, there is more interest in using RW to irrigate residential lawns. Using RW to supply a portion of the N for turfgrass growth may allow reductions in amounts of other N fertilizer sources used. It is important to determine the optimum combinations of water and nutrient applications to support turfgrass production without impairing groundwater through losses of nutrients from the landscape (Petrovic, 1990). However, few studies have focused on the degree to which residential turfgrass can use the N from RW following advanced treatment.

St. augustinegrass and zoysiagrass are the most common residential turf species in Florida. Nitrogen applications to turfgrass occur more frequently and in larger quantities than any other fertilizer-supplied nutrient because N is typically the most growth-limiting nutrient in turfgrass (Hochmuth et al., 2009). Current N fertilization recommendations for st. augustinegrass and zoysiagrass in Florida include a range of rates from 98 to 294 kg·ha⁻¹ N annually, depending on geographical region in the state and level of aesthetic preference (Trenholm et al., 2012). The typical N fertilizer application rate was 195 kg·ha⁻¹ N (about 4 lb/1000 ft² N) annually for both turf types in the northern Florida area. Greenhouse studies were conducted using these two most common turfgrass

types to determine if N from RW played a significant role in turfgrass nutrition. The goal of this research project was to determine if there is a fertilizer offset (a deduction that can be made in fertilizer N use) when RW containing N is used to irrigate turfgrass. Specifically, the objectives were (1) to compare the effects of RW-derived N and fertilizer-N on turfgrass growth and health, (2) to measure nutrient use efficiency of turfgrass with various N treatments, and (3) to evaluate the potential N leaching loss to the environment associated with various N treatments.

Materials and methods

SAND, RW, AND TURFGRASS SOURCES. Experiments were conducted in Envirotron greenhouse at the Environmental Horticulture Department on the campus of the University of Florida, Gainesville. Sand (obtained from a commercial sand quarry in Ocala, FL) was used for the media for these greenhouse studies conducted from July 2011 to Aug. 2012. Sand was used because it represents soils common in Florida. The chemical properties of the sand media are presented in Table 1. The sand was very low in N such that N in the unfertilized media would contribute little to plant growth and N would need to be supplied from the specific N treatments. Reclaimed water was supplied from a tap in the Envirotron greenhouse from the campus wastewater utility that uses advanced treatment. Chemical properties of the RW are presented in Table 2. Irrigation solutions were prepared in the greenhouse using RW or tap water and were stored in dark tanks on-site during the study period.

Inside the greenhouse, computer controlled end-wall exhaust fans, a wall-length evaporative-cooling pad humidifier, and an automatic roof vent were used to maintain environmental conditions. Greenhouse air temperature was maintained at an average 24 ± 6 °C, and relative humidity was maintained between 50% and 75% over the experimental period.

‘Floratam’ st. augustinegrass and ‘Empire’ zoysiagrass sods were supplied from a commercial sod farm in central Florida. Roots of all sods were washed with a tap water spray nozzle to remove residual soil and associated fertilizer nutrients and the sod pieces

Table 1. Chemical properties of the sand collected in June 2011 from the Keuka Sand Mine operated by Florida Rock Industries, Ocala, FL. Results are an average of three replicates.

	pH	NH ₄ ⁺ -N ^z	NO ₃ -N ^z	TKN ^z	Phosphorus			Mehlich-1 extractable			Mehlich-3 extractable		
					Iron	Magnesium	Calcium	Potassium	Phosphorus	Iron	Magnesium	Calcium	Potassium
Mean	5.5 ^y	0.7	0.1	7.0	2.6	2.5	33.3	0.6	1.1	2.6	5.7	48.6	2.4
SD	0.1	0.2	0.1	4.7	1.0	1.5	14.8	1.4	0.5	1.0	10.7	10.3	2.5

^zNH₄⁺-N = ammonia nitrogen extracted by 1 N potassium chloride, NO₃-N = nitrate nitrogen extracted by 1 N potassium chloride, TKN = total Kjeldahl nitrogen, which is the sum of NH₄⁺-N and organic N.
^y1 mg·kg⁻¹ = 1 ppm.

Table 2. Chemical properties of reclaimed water, tap water, and deionized water (control). Reclaimed water was delivered to the Envirotan greenhouse (Gainesville, FL) from the campus water treatment facility.

	Electrical conductivity		Total phosphorus ²	Orthophosphorus		Nitrate nitrogen	Ammonia nitrogen		Total Kjeldahl nitrogen		Iron	Potassium	Magnesium	Calcium
	pH	$\mu\text{S}\cdot\text{cm}^{-1}\text{ y}$		$\mu\text{g}\cdot\text{L}^{-1}\text{ y}$	mean (SD)		mg·L ⁻¹ y	mg·L ⁻¹ y						
Reclaimed water ^x	7.14 (0.32)	633 (164)	1,975 (1,205)	1,919 (1,235)		2.14 (1.48)	0.46 (0.67)	1.18 (0.82)	3.31 (1.73)	0.14 (0.02)	12.14 (1.40)	30.27 (3.17)	45.92 (2.13)	
Tap water	6.15	12	12	3		0.10	0.09	0.11	0.21	—	—	—	—	

¹Total phosphorus is organic phosphorus plus orthophosphorus. Nearly 100% of total phosphorus consisted of orthophosphorus. Total nitrogen is total Kjeldahl nitrogen plus nitrate nitrogen.
²1 $\mu\text{S}\cdot\text{cm}^{-1}$ = 1 $\mu\text{mho}/\text{cm}$, 1 $\mu\text{g}\cdot\text{L}^{-1}$ = 1 ppb, 1 $\text{mg}\cdot\text{L}^{-1}$ = 1 ppm.
^xResult of reclaimed water is the mean concentration of experimentation period (1 year).

^xTotal phosphorus is organic phosphorus plus orthophosphorus. Nearly 100% of total phosphorus consisted of orthophosphorus. Total nitrogen is total Kjeldahl nitrogen plus nitrate nitrogen.

^y1 μS·cm⁻¹ = 1 μmho/cm, 1 μg·L⁻¹ = 1 ppb, 1 mg·L⁻¹ = 1 ppm.

^zResult of reclaimed water is the mean concentration of experiment period (1 year).

were cut to fit the size of the growing tubs. Polyethylene storage tubs (42 × 33 × 15 cm) were used as growth containers. Each tub was fitted with a drain tube in the bottom toward one end to facilitate drainage and collection of leachate. The bottom of each tub was covered with washed pea gravel that was covered with a mesh cloth to minimize loss of sand media. The tubs were filled with sand media to a depth of 6 inches. Sod was placed on the sand surface and allowed to establish in the tubs for a period of 28 d, a period typical for establishing turfgrass outdoors. During the establishment period, no fertilizer was applied but the turf was sprinkler-irrigated (tap water) to maintain moisture at field capacity (10%) during the establishment period, which is a recommended practice in Florida, especially for N (Saxton and Rawls, 2006; Trenholm, 2009). Leaves of both st. augustinegrass and zoysiagrass sods were trimmed at 1 inch height above the sand surface at the beginning of the experiment. Pesticides were applied, as needed, based on visual pest identification. Bifenazate was applied for insects and azoxystrobin was applied for disease control when a problem, such as gray leaf spot (*Pyricularia grisea*), arose during the experiment period.

SAMPLE COLLECTION. Reclaimed water samples were collected at the greenhouse tap and were analyzed for electrical conductivity (EC), pH, N [nitrate N (NO₃-N), total Kjeldahl-N (TKN), ammonia N (NH₄-N)], total P, orthophosphate (ortho-P), iron (Fe), magnesium (Mg), potassium (K), and calcium (Ca) concentrations weekly. Two samples were collected during each sampling event with 30-min time interval. Tap water samples were similarly collected once per month and analyzed for the same parameters.

Turfgrass color, as determined by chlorophyll content was measured bimonthly by a reflectance chlorophyll meter (Field Scout CM-1000; Spectrum Technologies, Plainfield, IL). Measurements were conducted under natural light conditions and the instrument was calibrated before use following the procedures recommended by manufacturer.

Turfgrass in each tub was trimmed with scissors in fall (6 Sept., 20 Sept., 11 Oct. 2011), spring (27 Feb., 2 May, 5 June 2012), and summer (5 and 20

Aug. 2012) to maintain turf at the recommended mowing height (3 inches from soil surface for st. augustinegrass and 2 inches for zoysiagrass). All tissue samples were dried until constant weight at 65 °C. Dried samples were weighed and ground in a Wiley mill to pass a 2-mm screen. For each experimental unit (tub), dried and ground dry matter from all harvest dates in each harvest period (fall, spring, and summer) was combined and thoroughly mixed. For example, in the fall, each experimental unit had dry matter composited from three harvests. The mixed composited dry matter was sampled for laboratory tissue analyses. This process was repeated for the spring and summer harvest periods. At the end of the experiment (Aug. 2012), all final plant parts (roots and verdure) and thatch were harvested from a 3 inches wide slice of media in each tub simultaneously with the final clippings harvest. Verdure samples included the stolons and leaf blades remaining after the clippings were removed. Thatch samples consisted of all dead plant material above the soil surface after verdure was removed. Roots were washed free of media. Soil adhering to the tissue samples was removed by gentle washing with tap water.

SAMPLE ANALYSIS. Water samples (RW, tap water, and leachate) were immediately preserved on ice to maintain a sample temperature of <4 °C and delivered same day they were collected to the University of Florida Institute of Food and Agricultural Sciences Analytical Research Laboratory for analysis. The concentrations of NO₃-N, NH₄-N, and TKN were determined using a discrete autoanalyzer following U.S. Environmental Protection Agency (USEPA) method 351.2 (USEPA, 1993a). Total N was calculated as the sum of TKN and NO₃-N. The concentrations of total P and ortho-P were determined by the molybdenum-blue method after digestion with acidified ammonium persulfate following USEPA method 365.1 (USEPA, 1993b). The concentrations of dissolved macro- and microelements in water were determined using an inductively coupled plasma emission spectrometer (ICP) following USEPA method 200.7 (USEPA, 1994).

Soil samples were air-dried, ground using a mortar to break up clumps, and

passed through a 2-mm sieve before chemical analyses. Soil N ($\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$) was determined by shaking a 2.5 g air-dried soil sample in 25 mL of 2 M potassium chloride for 1 h. Concentrations of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ in the filtrate were determined with a discrete autoanalyzer. Total Kjeldahl N was determined from a 1-g soil sample digested with 2.0 g of Kjeldahl mixture and concentrated (12 M) sulfuric acid solution in an aluminum block digester for 1 h followed by semiautomated colorimetric analysis (USEPA method 351.2). Concentrations of soil available P and metals were determined by two extraction methods: (1) Mehlich-1 (1:4 ratio of soil/0.05 M hydrochloric acid + 0.0125 M sulfuric acid; 5-min reaction time) and (2) Mehlich-3 [1:10 ratio of soil/Mehlich-3 extraction solution (0.2 M acetic acid + 0.25 M ammonium nitrate + 0.015 M ammonium fluoride + 0.013 M nitric acid + 0.001 M ethylenediaminetetraacetic acid, pH 2.0); 5-min reaction time] (Mehlich, 1984). At the end of extractions, the supernatant was filtered before being analyzed by the ICP (USEPA method 200.7).

The plant samples were dried at 65 °C for 72 h and ground in a Wiley Mill to pass a 2-mm screen. Total Kjeldahl N concentration in plant tissue was determined from a 0.2-g ground plant sample digested with 2.0 g of Kjeldahl mixture and concentrated (12 M) sulfuric acid solution in an aluminum block digester for 1 h followed by semiautomated colorimetric analysis (USEPA method 351.2).

EXPERIMENTAL DESIGN. The experimental design was a factorial experiment in a randomized complete block design with four replications. The first factor consisted of two turf types: st. augustinegrass and zoysia-grass, and the second factor consisted of six N fertilizer treatments, tap water control, RW containing the base level N in the delivered RW, RW with additional 2, 6, and 10 $\text{mg}\cdot\text{L}^{-1}$ N, and a dry synthetic fertilizer control. All solutions involving RW began with the delivered RW with 3 $\text{mg}\cdot\text{L}^{-1}$ N, which is a mixture of $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ with a fluctuating $\text{NO}_3\text{-N}$: $\text{NH}_4\text{-N}$ ratio. Then additional N was added in the form of ammonium nitrate to increase the final delivered N concentrations to 5, 9, and 13 $\text{mg}\cdot\text{L}^{-1}$ N.

Media testing for P and K showed very low concentrations so P, K, and other macro- and micronutrients were added in the nutrient solution. Concentrations of major nutrients other than N (P, K, Ca, Mg) and minor nutrients [B, Cu, manganese (Mn), molybdenum (Mo), zinc (Zn)] were the same across all the treatments and supplied from a separate nutrient stock added to each N treatment irrigation solution. All turfgrass received the same amount of these nutrients in water-soluble forms at levels recommended to prevent deficiencies of these nutrients. Turf fertilized with the recommended synthetic fertilizer treatment received the equivalent of 195 $\text{kg}\cdot\text{ha}^{-1}$ N per year (about 0.227 g/tub N per month) in the form of dry ammonium nitrate (0.66 g) monthly. A zero-N control treatment was included where turfgrass was irrigated with tap water only.

The amount of irrigation to apply daily was determined as the amount needed to maintain the media at field capacity allowing negligible leaching. A typical irrigation rate was 300 mL/tub per day (about 2 mm per day). The application frequency was evaluated and adjusted every 3 d based on turf growth and weather. The irrigation frequency was 4 d per week in December and March, 3 d per week in January and February, and 7 d per week in the rest of the months of the year.

Near the end of the experiment in Aug. 2012 two leaching events were carried out (to simulate a leaching event) by applying 1000 mL tap water to each growing tub manually the week after the final nutrient application and then 2 weeks later. Leachate was collected from the bottom drainage port of each tub. The leachate volume was measured and a subsample was immediately delivered to the laboratory for determination of $\text{NO}_3\text{-N}$, TKN, and $\text{NH}_4\text{-N}$ concentrations. Leachate N loads were determined by multiplying the N concentration in the leachate from each tub by the leachate volume.

QUALITY CONTROL. All sample collection, handling, and chemical analyses were conducted according to the National Environmental Laboratory Accreditation Conference standards at the University of Florida Analytical Research laboratory under certification number Florida Department of Health E72850. Method reagent

blanks, spike samples, as well as certified standards from a source other than normal calibration standards, were included in the digestion or extraction process for every 20 samples. Percentage recovery of N ranged from 95% to 105%, meeting quality control standards for the project.

STATISTICAL ANALYSES. Significance of interaction and treatment effects was determined by analysis of variance (F test was significant at $P < 0.05$) using SAS (version 9.1 for Windows; SAS Institute, Cary, NC). Fisher's least significant difference values were used to determine the differences among the treatment means at the 0.05 P level.

Results and discussion

RECLAIMED WATER CHARACTERIZATION AND MONITORING. The pH of RW was stable during the year with an average of 7.14 (Table 2). The EC, a measure of salinity in the water, was 0.63 $\text{dS}\cdot\text{m}^{-1}$, which is lower than that reported previously by Pedrero and Alarcon (2009) of 2.8 $\text{dS}\cdot\text{m}^{-1}$ and by Evanylo et al. (2010) of 1.5 $\text{dS}\cdot\text{m}^{-1}$. A critical EC level (50% inhibition of growth) for warm season turfgrasses irrigation has been estimated to be below 3 $\text{dS}\cdot\text{m}^{-1}$ (Carrow and Duncan, 1998). Thus, the pH and EC of the RW in this study would not be expected to adversely affect turfgrass growth.

The University of Florida wastewater treatment facility uses the "biodenitro" process for wastewater treatment that involves alternating aerated and anoxic conditions to promote exit of N by denitrification. N concentrations of RW during 1 year are presented in Fig. 1. $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, and TKN concentrations were in the range of 0.06 to 6.16 $\text{mg}\cdot\text{L}^{-1}$, 0.03 to 3.07 $\text{mg}\cdot\text{L}^{-1}$, and 0.35 to 5.06 $\text{mg}\cdot\text{L}^{-1}$, respectively. The maximum total N concentration (sum of $\text{NO}_3\text{-N}$ and TKN) appeared on 19 Jan. 2012 at 11.22 $\text{mg}\cdot\text{L}^{-1}$. Total N concentrations of samples collected from all the other dates were less than 6.41 $\text{mg}\cdot\text{L}^{-1}$ (Fig. 1). Average concentrations of nutrients in RW, based on 1-year monitoring, are presented in Table 2. The average N concentrations of RW, based on 1-year weekly monitoring from the start of this research in July 2011, were 3.31 $\text{mg}\cdot\text{L}^{-1}$ total N with 2.14 $\text{mg}\cdot\text{L}^{-1}$ nitrate N and 0.46 $\text{mg}\cdot\text{L}^{-1}$ ammonia N. The

concentrations of the same constituents in tap water and deionized water are also included (Table 2). The total N concentrations of RW were 17 times the concentrations in tap water. There was no specific pattern for concentrations of all species of N during the monitoring period (Fig. 1). Concentrations of N in the source RW varied; therefore should be sampled over any experimental period. It was impossible to vary the treatment concentrations of N to follow the

changes in concentrations over the year. Therefore, we chose to use the average value of $3 \text{ mg}\cdot\text{L}^{-1}$ total N as the base concentration of N for the treatments involving RW.

RESPONSE OF TURF QUALITY AND CLIPPINGS YIELDS. The results of chlorophyll index measurements are presented in Fig. 2. There was no interaction of turf type and N treatment for effects on turfgrass quality or clippings yield. St. augustinegrass receiving tap water and unamended RW

and zoysiagrass receiving tap water had chlorophyll index levels less than 150 (Fig. 2). The chlorophyll index measurements with the remaining treatments were above 150, which could be indicative of turf quality that is visually acceptable. This result is consistent with Rowland et al. (2010) that turf chlorophyll index measured with the same method met the minimum acceptable visual quality requirement when above 146. The chlorophyll index could be used as indicator of turfgrass quality and soil cover. This is supported by previous studies that found correlations between chlorophyll index and turfgrass clipping yield, leaf hue, darkness, and density (Rowland et al., 2010). Chlorophyll level is also closely related to the leaf N nutrition status; higher chlorophyll levels occurred with the higher N rates (Errecart et al., 2012). The chlorophyll level could likely be used as an indicator of N status to optimize N inputs (Kruse et al., 2006). Low growth rate and lightly colored leaves were observed on turfgrass with the lower N treatments (less than $5 \text{ mg}\cdot\text{L}^{-1}$ N), which indicated N deficiency.

Plant dry matter yields were affected by turf type and N treatment (Table 3). Zoysiagrass accumulated more dry matter than st. augustinegrass. The verdure, thatch, and root dry matter were greater for zoysiagrass than st. augustinegrass (Table 3). Bowman et al. (2002) found

Fig. 1. Changes in concentrations of nitrogen (N) species in reclaimed water at the Envirotron greenhouse (Gainesville, FL) during 1 year [started from 18 July 2011 (week 0)]; $1 \text{ mg}\cdot\text{L}^{-1} = 1 \text{ ppm}$.

Fig. 2. Turfgrass chlorophyll level under different fertilizer treatments for st. augustinegrass (left) and zoysiagrass (right). Letter “R” for nitrogen (N) treatment refers to a dry fertilizer treatment based on the recommended N application rate for turfgrass in northern Florida. Values are averages of three measurements for each treatment. Means with the same letters are not significantly different by Fisher’s least significant difference 0.05; $1 \text{ mg}\cdot\text{L}^{-1} = 1 \text{ ppm}$.

greater root weight for st. augustinegrass than zoysiagrass. The dry weight of turfgrass clippings each season as a function of irrigation solution N level can be described by a quadratic model, increasing with N treatment to 9 mg·L⁻¹ of N, then leveling off. The dry weight of clippings for turf with the recommended N fertilizer was similar to dry weight with the RW N treatment of 9 mg·L⁻¹ or above in the spring and fall seasons. The clippings dry matter was greater with the synthetic fertilizer treatment in the summer. N supply from unamended RW for the period of most rapid growth (summer) was not sufficient to maximize clippings yield.

The desired turfgrass growth minimizes clipping yield (minimizes mowing frequency) while achieves acceptable turfgrass quality (Carrow, 2012). The results for turfgrass growth and quality indicated that irrigation treatments with RW greater than or equal to 5 in the spring or summer and 9 mg·L⁻¹ in the fall could avoid excessive growth with acceptable turf quality. These results were from turfgrass growing in containers requiring frequent irrigation and would need to be confirmed in outdoor studies.

There was no interaction of N treatment and turfgrass species for

effects on N concentration in clippings (Table 4). Nitrogen treatment affected the TKN concentrations of plant parts each season: clippings ($P < 0.01$), thatch ($P < 0.05$), and verdure ($P < 0.01$), whereas the TKN concentration in roots was unaffected by N treatment (Table 4). TKN concentration of clippings increased linearly with N level in the irrigation solution. There were no differences in tissue N concentration between the recommended N fertilizer treatment and treatments with 9 and 13 mg·L⁻¹ N from RW. This result shows that the treatments with N above 9 mg·L⁻¹ had the same effect on turf tissue N concentration as the recommended synthetic N fertilizer. Clippings from st. augustinegrass had greater N concentrations than zoysiagrass in the fall season. Clippings from zoysiagrass had greater N concentration than st. augustinegrass in the spring season, and concentrations were similar in the summer. The sufficient tissue N concentration range is 1.5% to 3.5% for these turfgrasses (Sartain, 2001).

Total plant N uptake was calculated as the product of tissue N concentration and dry weight for all parts of turfgrass and then summed over plant parts (clippings, verdure, thatch,

and root). The total N uptake by turfgrass was affected by N treatments (Fig. 3). The treatments with applied N of 9 and 13 mg·L⁻¹ had the same effect on turf N uptake as the recommended N fertilizer program.

PLANT N RECOVERY. Percent N recovered by turfgrass during the experimental period (1 year) was calculated by dividing the plant N uptake by total N input for the whole year (Table 5). The source of N in the turfgrass with the control treatment irrigated by tap water was the N remaining in the sod and natural N input (e.g., atmospheric deposition). Plant N uptake in plants with the other treatments resulted from N in the RW, synthetic N, and atmospheric N. These amounts were calculated by subtracting the control turf N uptake from the total N uptake with each treatment. N recovery was in the range of 13% to 52% for st. augustinegrass and 21% to 84% for zoysiagrass overall N treatments (Table 5). The highest recovery for both turf types was found when the N solution was 9 mg·L⁻¹.

Reclaimed water with total N at 9 and 13 mg·L⁻¹ with 300 mL/tub irrigation rate, resulted in total N amounts added monthly of 0.054 and 0.090 g/tub, respectively, which

Table 3. Effect of nitrogen treatments on dry weight accumulation of turfgrass plant parts. Multiple clippings from the same season were mixed for total Kjeldahl nitrogen analysis. Data are for the concentration in the composite of the dry matter mixture.

	Clippings (Fall 2011)	Clippings (Spring 2012)	Clippings (Summer 2012)	Verdure	Thatch	Root
	-----g/tub ^z -----					
Nitrogen treatment						
(total nitrogen mg·L ⁻¹) ^y						
0	13.7 c ^x	12.9 c	7.1 c	11.1 a	7.5 a	14.8 a
3	15.9 c	18.6 b	9.1 b	16.6 a	6.5 a	12.4 a
5	18.7 b	26.2 ab	11.5 b	19.2 a	9.1 a	12.6 a
9	27.7 a	29.9 ab	12.9 b	15.9 a	6.4 a	11.0 a
13	29.5 a	27.2 ab	12.9 b	16.4 a	7.9 a	16.7 a
Recommended	29.4 a	32.5 a	17.3 a	16.1 a	5.6 a	8.3 a
Trend	Quadratic	Quadratic	Quadratic	—	—	—
Turf type						
St. augustinegrass	23.0	18.8	8.0	9.1	4.8	9.7
Zoysiagrass	20.7	33.6	16.3	22.6	9.5	15.6
Summary of ANOVA effects ^w						
Turf (T)	NS	**	**	**	*	*
N treatment (N)	***	**	*	NS	NS	NS
T × N	NS	*	NS	NS	NS	NS

^z1 g per 1386-cm² (214.8 inch²) tub = 7.2150 g·m⁻² = 0.2128 oz/yd².

^yNitrogen treatment include irrigation with reclaimed water with additional nitrogen supplied from ammonium nitrate to achieve 5, 9, and 13 mg·L⁻¹ nitrogen solutions, and with the recommended synthetic fertilizer treatment received the equivalent of 195 kg·ha⁻¹ (174.0 lb/acre) nitrogen per year; 1 mg·L⁻¹ = 1 ppm

^wValues within a column by the same letter do not differ at $P = 0.05$.

NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

Table 4. Effects of treatment on plant tissue total Kjeldahl nitrogen concentration of turfgrass. Multiple clippings from the same season were mixed for Total Kjeldahl nitrogen analysis. Data are for the concentration in the composite of the dry matter.

	Clippings (Fall 2011)	Clippings (Spring 2012)	Clippings (Summer 2012)	Thatch	Root	Verdure
	----- (mg·g ⁻¹) ^z -----					
Nitrogen treatment						
(total nitrogen mg·L ⁻¹) ^y						
0	15.3 b*	13.2 b	14.3 b	5.9 b	8.68 a	6.9 b
3	16.3 b	12.7 b	14.9 b	6.5 ab	8.4 a	7.7 a
5	18.2 a	17.0 a	14.9 b	6.6 ab	7.6 a	7.2 ab
9	18.9 a	17.4 a	15.4 ab	6.8 b	8.5 a	7.8 a
13	21.1 a	15.9 a	15.8 a	7.57 b	7.6 a	7.8 a
Recommended	19.1 a	15.7 a	15.7 a	7.2 b	7.7 a	8.5 a
Trend (nitrogen rate)	Linear	Linear	Linear	—	—	—
Turf type						
St. augustinegrass	19.5	11.8	15.4	6.6	9.7	7.1
Zoysiagrass	16.8	17.1	15.3	6.9	6.4	8.2
Summary of ANOVA effects ^w						
Turf (T)	*	**	NS	NS	**	*
N treatment (N)	**	**	**	*	NS	**
T × N	NS	NS	NS	NS	NS	NS

^z1 mg·g⁻¹ = 1000 ppm.

^yNitrogen treatment include irrigation with reclaimed water with additional N supplied from ammonium nitrate to achieve 5, 9, and 13 mg·L⁻¹ nitrogen solutions, and with the recommended synthetic fertilizer treatment received the equivalent of 195 kg·ha⁻¹ (174.0 lb/acre) nitrogen per year; 1 mg·L⁻¹ = 1 ppm.

^wValues within a column with the same letter do not differ at *P* = 0.05.

NS, *, **, *** Nonsignificant or significant at *P* < 0.05, 0.01, or 0.001, respectively.

Fig. 3. Turfgrass nitrogen (N) uptake under different fertilizer treatments for st. augustinegrass (left) and zoysiagrass (right). Letter “R” for N treatment refers to a dry fertilizer treatment based on the recommended N application rate for turfgrass in northern Florida. Clippings 1–3 refer to clipping collected in the season of Fall 2011, Spring 2012, and Summer 2012, respectively. Values are averages of four replicates of each treatment. Means for total plant uptake with the same letters are not significantly different by Fisher’s least significant difference 0.05; 1 g per 1386-cm² (214.8 inch²) tub = 7.2150 g·m⁻² = 0.2128 oz/yard².

was less than half of that added from the recommended rate of synthetic fertilizer (0.227 g N). Turfgrass used the N in RW and achieved acceptable

quality with total N at 9 and 13 mg·L⁻¹. Our results show that N contained in RW can be a significant source of N for turfgrass nutrition.

N LEACHING FROM TURFGRASS. Reclaimed water is a dilute nutrient solution; therefore, N can be leached under excessive application rates of

Table 5. Effects of turfgrass type and nitrogen (N) treatment on N recovery for the whole year.

N treatment (total N mg·L ⁻¹) ^z	Plant N content	Plant N uptake from anthropogenic input	N anthropogenic input			Recovery ^y %
			Fertilizer	Reclaimed water source	Total	
			-----mg/tub per yr ^x -----			
St. augustinegrass						
0	580 ^z	0	0	0	0	—
3	760	180	0	420	420	43 b ^w
5	990	410	0	780	780	52 a
9	1,340	760	0	1,500	1,500	51 a
13	1,410	830	0	2,220	2,220	37 b
Recommended	1,220	640	4,990 ^v	0	4,990	13 c
Zoysiagrass						
0	880 ^z	0	0	0	0	—
3	1,090	200	0	420	420	49 b
5	1,540	660	0	780	780	84 a
9	2,200	1,320	0	1,500	1,500	88 a
13	1,760	880	0	2,220	2,220	40 b
Recommended	1,940	1,060	4,990	0	4,990	21 c

^zControl treatment N from the original turf plant and atmospheric N deposition; 1 mg·L⁻¹ = 1 ppm.^yPlant N uptake from anthropogenic input being divided by the N anthropogenic input year for a whole year.^x1 mg per 1386-cm² (214.8 inch²) tub = 7.2150 mg·m⁻² = 1.0299 oz/acre.^vValues within a column with the same letter do not differ at *P* = 0.05.^vN application as 195 kg·ha⁻¹ (174.0 lb/acre) nitrogen per year.

Table 6. Effect of treatments on nitrogen loads in leachate in two leaching events

Nutrient treatment (total nitrogen mg·L ⁻¹) ^z	Leaching events							
	1				2			
	Nitrate nitrogen	Ammonia nitrogen	Total Kjeldahl nitrogen	Total nitrogen	Nitrate nitrogen	Ammonia nitrogen	Total Kjeldahl nitrogen	Total nitrogen
-----μg/tub ^z -----								
0	22 b ^y	41 b	298 b	320 b	18 a	29 a	218 a	236 a
3	19 b	27 c	268 b	286 b	17 a	29 a	169 a	186 a
5	9 c	14 c	221 b	230 b	15 a	33 a	198 a	213 a
9	17 b	30 b	281 b	298 b	17 a	35 a	164 a	180 a
13	12 b	35 b	237 b	248 b	15 a	35 a	151 a	165 a
Recommended	76 a	113 a	555 a	631 a	24 a	63 b	175 a	200 a
Turf								
St. augustinegrass	29	47	330	359	24	39	184	209
Zoysiagrass	23	39	290	312	11	35	174	185
Summary of ANOVA effects ^x								
Turf (T)	NS	NS	*	*	*	*	NS	*
Nutrient treatment (N)	**	**	*	*	NS	NS	NS	NS
T × N	NS	NS	NS	NS	NS	NS	NS	NS

^z1 mg·L⁻¹ = 1 ppm, 1 μg per 1386-cm² (214.8 inch²) tub = 7.2150 μg·m⁻² = 0.0010 oz/acre.^yValues within a column by the same letter do not differ at *P* = 0.05.NS, *, **Nonsignificant or significant at *P* < 0.05 or 0.01, respectively.

RW. Two leaching events were applied near the conclusion of this experiment in Aug. 2012 to test the hypothesis that amounts of leached N will be similar with various irrigation rates. Leachate N loads were determined by multiplying the concentration of N in the leachate from each tub with the leachate volume (Table 6).

There was no interaction between N treatment and turf type for effects on amounts of leached N. Nitrogen treatment affected the total N loads for the first leaching event. More N was lost with the synthetic fertilizer treatment compared with all other N treatments. There were no differences in N lost among the tap water and all

RW treatments. The total N loss with synthetic N was 2-fold the N lost with the remaining treatments for the first leaching event. Perhaps more N was lost with the synthetic N treatment because more N was applied in monthly applications compared with small daily amounts with the RW treatments. Greater amounts of residual

N were available for leaching with the synthetic treatment. The differences in N leached between N treatments for the second leaching event were not significant. In both leaching tests, more N was lost from st. augustinegrass compared with zoysiagrass. The length of time between fertilizer applications and leaching rainfall or irrigation determines the extent of nutrient losses from turfgrass systems (Petrovic and Easton, 2005). In the current study, N inputs from RW receiving advanced treatment were negligible. Hayes et al. (1990a) conducted a study on irrigation of turfgrass with RW receiving secondary treatment and found that elemental concentrations in leachate increased when the RW contained significant amounts of $\text{NH}_4\text{-N}$ (up to $28.6 \text{ mg}\cdot\text{L}^{-1}$).

Conclusions

N concentrations in the RW varied throughout the year, so that calculations of fertilizer offsets will need to take into account these variations. Turfgrass produced more biomass and took up more N in response to increased N delivery. There was no difference in turfgrass growth with the base level N in the delivered RW compared with tap water. As more N was added to the base RW, turfgrass growth increased. Similar growth resulted from RW with 9 or $13 \text{ mg}\cdot\text{L}^{-1}$ total N compared with monthly applications of the current recommended commercial fertilizer N rate in northern Florida. Although growth was increased as N concentration in the RW increased from 5 to $9 \text{ mg}\cdot\text{L}^{-1}$, turfgrass quality (color) was acceptable with $5 \text{ mg}\cdot\text{L}^{-1}$ total N. The N concentrations in RW from advanced wastewater treatment facilities in the current study were too low ($3 \text{ mg}\cdot\text{L}^{-1}$ N) to benefit turfgrass and achieve acceptable quality. A RW facility producing RW with $5 \text{ mg}\cdot\text{L}^{-1}$ or above would provide enough N for a response in turfgrass growth reducing the need for fertilizer. Leaching of N was unaffected by RW treatment, but more N was leached with the synthetic fertilizer treatment compared with RW. Leaching of N with all treatments was negligible. These greenhouse studies show that N from RW can be beneficial for turfgrass growth and health but the concentration of N in RW with advanced treatment would need to be at least $5 \text{ mg}\cdot\text{L}^{-1}$. Outdoor

field-scale experiments are needed to validate the results from these greenhouse studies.

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