Water **2010**, *2*, 685-701; doi:10.3390/w2030685

OPEN ACCESS

water

ISSN 2073-4441

www.mdpi.com/journal/water

Article

Reclaimed Water for Turfgrass Irrigation

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Received: 4 August 2010; in revised form: 17 September 2010 / Accepted: 19 September 2010 / Published: 21 September 2010

Abstract: Sustainable irrigation of turfgrass grown on coarse-textured soils with reclaimed water must avoid detrimental effects of soluble salts on plant growth and soil quality and groundwater enrichment of nitrogen (N) and phosphorus (P). The purpose of this study was (1) to investigate the effects of irrigating with municipal reclaimed water containing higher concentrations of soluble salts than potable water on turfgrass growth and quality and (2) to compare the effects of reclaimed and potable water on turfgrass assimilation and leaching of N and P. A sand-based medium plumbed to supply potable and reclaimed water and instrumented with lysimeters to collect leachate was planted with hybrid bermudagrass (*Cynodon dactylon x Cynodon transvaalensis var.* Tifsport) and creeping bentgrass (*Agrostis stolonifera var.* L-93). Both species produced high quality turfgrass with the reclaimed water. Although both grasses are moderately or highly salt tolerant when fully established, the bermudagrass growth and quality were reduced by the reclaimed water upon breaking dormancy, and its N use during this period was reduced. Continuous use of reclaimed water of the quality used in the study poses a potential soil Na accumulation problem. Both turfgrasses assimilated high amounts of N and P with minimal potential losses to groundwater.

Keywords: *Agrostis*; *Cynodon*; nutrient leaching; water quality

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1. Introduction

Soil moisture is often limiting for optimum quality and growth of turfgrass during the spring through fall period in southeastern Virginia. Reclaimed water may be a more reliable irrigation source than potable water during times when potable water supplies are limited, such as periods of extreme summer drought.

The Hampton Roads Sanitation District (HRSD) operates the Virginia Initiatives Plant (VIP), a wastewater treatment facility in Norfolk, Virginia that employs biological nutrient removal to generate an effluent containing low concentrations of nitrogen (N) and phosphorus (P). Based on preliminary turfgrass irrigation studies at the VIP, Evanylo *et al.* [1] discovered that the constituents in the recycled water that pose the greatest agronomic and environmental risk are likely to be dissolved solids, nitrogen (N), and phosphorus (P). Potential problems that may arise from the use of such effluent for irrigating turfgrass include: (1) high soluble salt, Na, or Cl concentrations may impair plant growth and quality, (2) high concentrations of Na may disperse soil colloids and degrade soil structure, and (3) excessive concentrations of N and P may contaminate ground and surface water [2].

Carrow and Duncan [3] and the USGA [2] have described the effects of recycled water for turfgrass irrigation on soil, plant and water quality. Irrigation of turfgrass with saline wastewater effluent can cause stress and injury by water deficiency, ion toxicity, and ion imbalances. Salt-induced plant water stress is termed "physiological" or "osmotic" drought. Limited water uptake reduces cell turgor, leaf size, photosynthesis, carbohydrate storage, and rooting. Such effects may result in a lower performing turfgrass that may have poor tolerance to and recovery from wear [3].

The potential for physiological drought can be determined by measuring the electrical conductivity of the effluent or ECw. The critical EC for creeping bentgrass and hybrid bermudagrass performance have been estimated as 3–6 dS m^{-1} and 6–10 dS m^{-1} [3], respectively. The electrical conductivity of the VIP effluent has ranged from 0.9 to 2.8 dS m^{-1} [1]; thus, turfgrass performance would not be expected to be adversely affected by soluble salts from the VIP recycled water.

Continuous use of the saline irrigation source without flushing of salts by rainfall may result in an accumulation of salts detrimental to turfgrass performance. High concentrations of salts in the soil can induce drought symptoms in plants due to reduced osmotic potential [4]. A 50% inhibition of growth has been reported for bentgrass and bermudagrass grown in soil at electrical conductivity (ECe) values of 8 dS m^{-1} and 22 dS m^{-1}, respectively. Soil ECe values ranged from 0.1 to 0.5 dS m^{-1} after a growing season of irrigation with recycled effluent at the HRSD VIP in 2001, but ample rainfall prevented a great reliance on the recycled water to meet soil moisture needs.

Salt-induced physiological drought is caused by high total salinity without regard to the salt type. By contrast, ion toxicity is caused by specific ions, such as Na^+, Cl^-, and H_3BO_3, which are directly toxic to root or shoot tissues [3]. Injury to foliage occurs at >70 mg Na L^{-1} and >100 mg Cl L^{-1}, and to roots at 70 to 210 mg Na L^{-1} and 70 to 355 mg Cl L^{-1} [3].

High levels of Na, Cl, and other ions can induce nutrient imbalances and deficiencies of Ca, K, N, Mg, Mn, and P [3]. Evanylo *et al.* [1] did not discover any tissue nutrient deficiencies, but the results were obtained from a non-replicated demonstration study; thus, further research is required to assess the potential for plant nutrition effects.

Long standing recommendations for irrigating with water that contains a high soluble salt content includes using a leaching fraction of 10% [5]. The leaching fraction is the amount of irrigation water above that required by the crop to maintain acceptable root zone salinity. It remains to be seen whether irrigation rates of reclaimed water necessary to prevent excessive salt accumulation in the soil profile will result in acceptable NO_3-N and P leaching amounts.

Bentgrass and bermudagrass are turfgrass species whose extensive root systems are capable of high water use, excellent potential as nitrogen assimilators, and high moisture tolerance [6]. Such crops can remove a highly mobile ion like nitrate from a volume of water larger than that transpired by the plant through a combination of mass flow and diffusion.

Hayes *et al.* [7] demonstrated that the use of wastewater effluent to supply adequate water for bermudagrass growth in Arizona resulted in increased concentrations of soil nitrate. It is important to determine the optimum combinations of water and nutrient loads to support turfgrass production without impairing groundwater. King and Balogh [8] were able to significantly decrease offsite nitrate N transport with a resulting improvement in water quality by reducing the application rates of fertilizers as irrigation rates were increased.

Phosphorus transport to surface water is becoming an increasing concern due to the potential for eutrophication. Irrigation with recycled water to supply turfgrass consumptive water use can potentially increase soil P to concentrations greater than those that can be held by coarse-textured soils. Hayes *et al.* [7] measured significant increases in soil P following the application of sewage effluent to irrigated bermudagrass. Tesar *et al.* [9] determined that most of the phosphorus in a wastewater effluent applied over a 5-year experiment was not removed by the plants but remained in the top 15 cm of a fine loamy soil. Little research has been conducted to measure the potential for P in recycled water to be transported through coarse-textured turfgrass soils because the importance of P transport to surface water is such a recent issue.

The characteristics of recycled water and the soil influence the design of a land application system for crop production [10]. Allhands and Overman [10] measured decreases in organic matter, cation exchange capacity, exchangeable acidity, and available P with soil depth and increases in bermudagrass dry matter production and N and K uptake. Menzies *et al.* [11] determined that P adsorption capacity of sandy soils was reduced by continual high irrigation rates, which decreased the application site life calculated on the basis of original P sorption capacity.

Further research on soil and plant effects of long term application of recycled water onto sand-based turfgrass systems is required to ensure maintenance of plant quality and to protect water quality. The objectives of this research were to compare the effects of potable and reclaimed (non-potable) water on (1) soil chemical properties that may be affected by irrigation water of varying ionic composition; (2) turfgrass nutrient uptake, growth, and quality and (3) leaching of N and P.

2. Materials and Methods

We coordinated the construction of a turfgrass study site at the HRSD VIP in Norfolk beginning in summer 2003, when a sand-based root zone meeting United States Golf Association [12] golf green specifications was constructed (Picture 1). The research plots were plumbed to supply Norfolk city potable water and non-potable water reclaimed at the HRSD VIP to 12 separate plots in which two turfgrass species were to be established. The dimensions of each of the 12 plots were 3 m (width) by 7.5 m (length). A 3 m alley separated each plot.

Each of the 12 plots was instrumented with two lysimeters to collect leachate that percolated through the sand medium. The lysimeters consisted of polyvinyl chloride (PVC) pipe fashioned into a trough by cutting lengthwise pieces 30 cm long and 10 cm in diameter (Picture 2). The troughs were capped at one end and plumbed at the other end to drain though PVC pipes as conduits to the edges of the plots (Picture 3). The collection troughs were situated approximately 2 m and 4 m, respectively, from the lower end of each plot, 0.5 m from the outside edges of each plot, and 0.20 m below the sand medium surface. The piping was placed at a 2% slope to enable the leachate collected in the troughs to drain by gravity to the lower end of the plots, where the leachate accumulated in a short, capped PVC pipe prior to sampling. The troughs were filled with acid-washed coarse gravel and sand from the greens' profile.

Hybrid bermudagrass (*Cynodon dactylon x Cynodon transvaalensis* var. Tifsport) and creeping bentgrass (*Agrostis stolonifera* var. L-93) were established on six plots each in spring 2004 (Picture 4). The bentgrass was seeded and the bermudagrass was sprigged in July 2004. Only potable water was used as an irrigation source during establishment. The Tifsport variety of bermudagrass is a warm-season grass that is very deep-rooted and spreads by both stolons and rhizomes. It is commonly used in the Hampton Roads area as the main grass on golf course fairways, tees, and roughs; and is also used on athletic fields and on some home lawns, where it remains green from approximately April 15 to November 30. Tifsport is favored for its excellent wear, heat, drought, disease, and salt tolerance. 'L-93' creeping bentgrass is a cool-season turfgrass that spreads by stolons. It is used primarily for putting greens (0.28 to 0.38 cm cutting heights) in Eastern Virginia and less often for golf fairways (1.3 cm cutting height). Creeping bentgrass requires great care to maintain an acceptable performance level during eastern Virginia summers, but it is used because golfers greatly prefer its density, texture, and its 12-month color retention. No other C3 grass can maintain density at these required low mowing heights. Bentgrass is moderately salt tolerant.

The experimental design was a 2×2 factorial, completely randomized block consisting of two turfgrass (bermudagrass and bentgrass) and two water (Norfolk city potable and VIP reclaimed) treatments. Each treatment was replicated three times. The reclaimed water was generated at the HRSD VIP from wastewater subjected to secondary treatment and a suspended-growth biological reactor divided into anaerobic, anoxic, and aerobic staged zones for removal of nitrogen and phosphorus (http://www.hrsd.com/treatmentplants.htm). The effluent used for the source of the reclaimed water in the study was treated by chlorination during 30 minutes of contact.

The water treatments were delivered to the appropriate plots via a subsurface irrigation system which was plumbed to provide reclaimed and potable water to the turfgrass plots at known rates (following calibration) by pop-up sprinkler heads arranged around the perimeter of each plot to ensure equal spray coverage. Irrigation was supplied manually by a sports turf professional under contract to the HRSD. Water was applied every 3 or 4 days unless rainfall of at least 6 mm was measured in rain gauges installed on each plot. The amounts of reclaimed and potable water supplied were measured with rain gauges each time the irrigation was applied during the April to October 2005 growth period. On-site natural precipitation was also measured daily during this time.

Picture 1. Construction of the sand-based study site in summer 2003.

Picture 2. Lysimeter collection trough embedded in sand medium.

Picture 3. Lysimeter collection containers extending beyond the lower end of the instrumented turfgrass plot (summer 2004).

Picture 4. Establishment of turfgrass showing 5-day old bentgrass seedlings (foreground) and bermudagrass sprigged plots (background) on July 29, 2004.

Assessment of quality of the irrigation water was based on monthly mean analyses of wastewater effluent and City of Norfolk potable water analyzed by HRSD analytical technicians (Table 1). Analyses were conducted using Standard Methods for the Examination of Water and Wastewater [13]. Loading rates of water constituents were calculated as the products of the constituents' concentrations and irrigation volumes.

Table 1. Chemical and physical analysis of potable (2005) and reclaimed, non-potable (2005 and 2006) water used to irrigate the turfgrass, and groundwater standards for southeastern Virginia. Values are means of analyses conducted several times per week throughout the application period.

Parameter	Potable–2005	Reclaimed–2005	Reclaimed–2006	Groundwater standards
pH	7.53	7.00	7.02	6.5–9.0
Electrical conductivity, dS m^{-1}	0.27	1.5		
BOD_5, mg L^{-1}	<2	8.2	4.0	
Total suspended solids, mg L^{-1}	1.0	4.5	4.8	1000
Total Kjeldahl nitrogen, mg L^{-1}	0.8	2.1	2.0	
NO_3-N, mg L^{-1}	0.6	5.2	6.5	5.0
Total phosphorus, mg L^{-1}	0.25	0.42	0.34	
Sodium, mg L^{-1}	36	238		100
Chloride, mg L^{-1}	16	317	420	50

We estimated that the amounts of N and P supplied by irrigating with the reclaimed and potable water would necessitate supplemental fertilizer N and P based on previous analyses [1]. The entire turfgrass nutrient requirements were, therefore, provided by commercial fertilizer as supplied according to Virginia Cooperative Extension Soil Test recommendations for turfgrass [14].

Summer to fall 2004 was used as the establishment period for the turfgrasses. Turfgrass was maintained according to typical golf course maintenance standards for mowing heights, mowing frequency, and pesticide use [15]. Diseases, weeds, and insects were scouted and controlled on an early curative basis. Our goal was to maintain the plots to a quality level required at a mid to high expectation golf course fairway. A 19–2–19 (N–P_2O_5–K_2O) fertilizer was used each year to supply 202 kg N ha^{-1} to the bentgrass and 253 kg N ha^{-1} to the bermudagrass, regardless of irrigation source.

The effects of water source on turfgrass visual quality, wear tolerance and recovery, root growth, and tiller density were assessed periodically beginning after establishment. Root mass was measured in October 2004 and in April 2005 and tiller density was measured in October 2004 and August 2005. Turfgrass growth and quality monitoring were conducted from July to December 2004 and from May to October 2005 as described below.

Wear tolerance and recovery: A studded roller was used to simulate spring (May, 2005), summer (July, 2004 and 2005), and fall (September 15 to October 15, 2004 and 2005) soccer seasons consisting of 20 “matches” each. Five matches per week were simulated for one month. Four days clippings were collected each week from May through October 2005 for determination of biomass production and N and P assimilation. Visual turf quality (density, uniformity, and color) ratings were determined monthly from July through December 2004 and from May through October 2005. Ratings of visual quality are a standard accepted practice amongst turf scientists for making treatment comparisons in terms of perceived aesthetic value. Turf quality was rated on a 1–9 scale with 1 = dead/dormant/completely brown turf, 6 = a minimally acceptable rating, and 9 = highest possible quality. Quality was based on color, leaf texture (width), uniformity of coverage, and tiller density.

Two 10-cm diameter, 10 cm deep plugs per plot were sampled in October 2004 and August 2004 and 2005 to measure tiller density. Roots were washed from the plugs and dried at 70 °C for measurement of total root biomass.

The bermudagrass and bentgrass were mowed every two to three days or at least three times per week to a 12 mm height. Collection of plant growth and N and P plant uptake data were initiated in spring 2005 after establishment periods for the bermudagrass (July to October in 2003 and May to October 2004) and bentgrass (March to December 2004). Clippings of each species were collected each week throughout the 2005 growing season and during May and July only in 2006 for calculation of biomass production, N and P leaf clipping concentrations and aboveground N and P assimilation. All samples were dried in a forced air oven at 70 °C for 72 h or until constant mass was achieved, weighed for dry matter, and ground in a stainless steel Wiley mill to pass a 0.5-mm sieve in preparation for chemical analysis. Plant tissue was digested and analyzed for total Kjeldahl N and P using block digestion and QuickChem autoanalyzer industrial methods [16] to determine monthly N and P concentrations and (in conjunction with dry matter production) assimilation.

Ten soil cores were sampled to a 10-cm depth from each plot at the beginning (July 2004 and April 2005 and 2006) and end (October 2005 and August 2006) of each growing season for analysis of routine soil test parameters. The samples were air-dried and passed through a 2-mm sieve in preparation for chemical extraction. Soil samples were analyzed for pH in soil-water mix; Bray 1-P; ammonium acetate exchangeable K, Ca, Mg, Na, and H for calculation of base saturation and exchangeable sodium percentage (ESP); and cation exchange capacity using standard soil test procedures [17] and organic matter by Walkley-Black wet oxidation [18].

Leachate was collected monthly from each lysimeter, volumes were determined, and subsamples were analyzed colorimetrically for NH_4-N and NO_3-N with a QuickChem autoanalyzer (Methods No. 12-107-04-1-B and No. 12-107-06-2-A [19]) and total P by EPA 365.4 [20] in order to calculate leachate N and P masses.

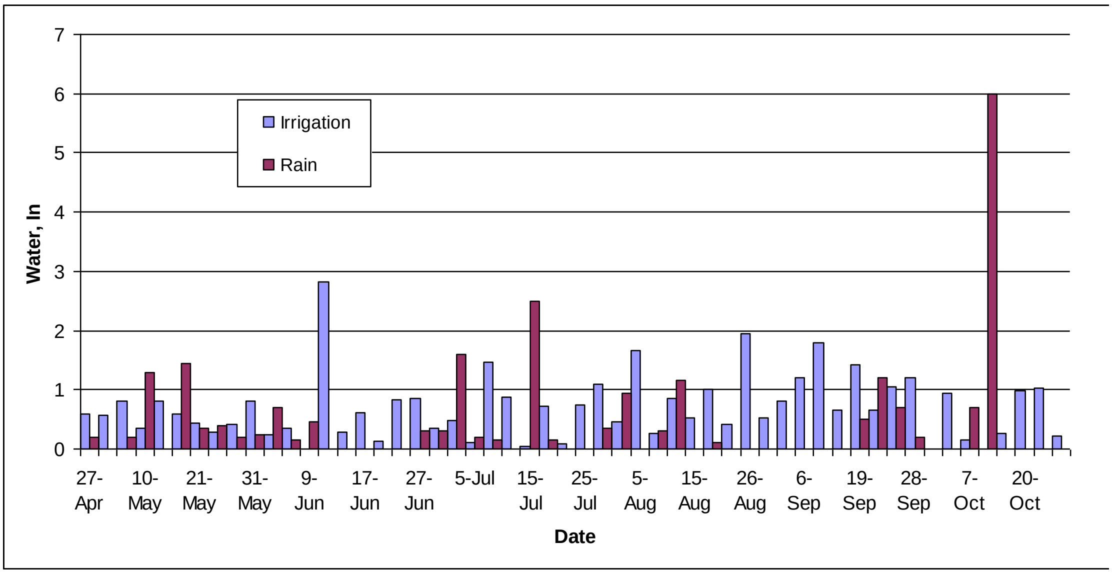
All data were statistically analyzed by analysis of variance, and mean separations were calculated using least significant differences at a 0.05 probability level employing SAS [21].

3. Results

3.1. Irrigation Volume

The combined amounts of irrigation and rainfall applied from April through October 2005 were considerably higher than provided during a normal season (Figure 1) as the turfgrass management contractor irrigated to ensure a high leaching fraction and minimal turfgrass drought stress. Mean historical (1971–2000) precipitation for this region averages 677 mm (26.7 inches) during this same period (http://cdo.ncdc.noaa.gov/climatenormals/clim81/VAnorm.pdf).

Figure 1. Rainfall and irrigation applied to the experimental site from April to October, 2005. The cumulative amounts of water were 584 mm (23 inches) from rainfall and 1370 mm (54 inches) from irrigation.



3.2. Irrigation Water Composition

Characteristics of the reclaimed water that caused its quality to be lower than the potable water included total suspended solids (TSS), biochemical oxygen demand (BOD_5), electrical conductivity (EC), and concentrations of Na and Cl (Table 1). Elevated levels of organic matter likely contributed to the higher concentrations of BOD_5 and TSS, but TSS were still several magnitudes of order lower than groundwater standards for southeastern Virginia. The higher concentrations of Na and Cl in the reclaimed water contributed to the higher EC, all of which may potentially adversely affect turfgrass growth; however, EC and concentrations of Na and Cl do not appear to be high enough to cause short term damage. The reclaimed water also contained higher concentrations of TKN, NO_3-N, and total P than did the potable water.

3.3. Soil Response to Irrigation

The sand medium, as expected, contained very low capability to hold essential plant nutrient cations (cation exchange capacity = 1.33 cmol (+) kg^{-1}), which was due to the low contents of clay and organic matter (10 mg g^{-1}, or 1%). Initial nutrient content was also low and was increased during the course of the study by the addition of fertilizer N, P, and K and by P and cations applied with the reclaimed water (Table 2). Phosphorus increased from 6 to 13 mg kg^{-1}, and K, Mg, Ca, and Na also increased between the start of the reclaimed water application in July 2004 and the final soil sampling in August 2006. Of the cations that were higher in the sand medium irrigated with reclaimed than with potable water, Na was of particular interest due to its potential to adversely affect soil and plant quality.

Table 2. Effects of potable (pot) and reclaimed (recl) irrigation treatments on soil properties.

Soil property	July 2004	April 2005		October 2005		April 2006		August 2006	
		Pot	Recl	Pot	Recl	Pot	Recl	Pot	Recl
pH	5.87	6.28		4.50	4.85	5.40	6.40	5.70	6.40
Bray 1-P	6	8	10	17	19	17	13	14	12
Extract K, mg/kg	22	37	24	67a	42b	52	50	53	50
Extract Mg, mg/kg	27	20b	36a	38	50	26b	53a	29b	57a
Extract Ca, mg/kg	120	163	139	185	237	133	190	130	163
Extract Na, mg/kg	NA[2]	10b	39a	26b	58a	24b	92a	19b	91a
	% cation saturation								
K	5	7.4	5.0	5	3	9	7	9	7
Mg	20	14b	21a	9	12	14b	22a	17	24
Ca	52	62	53	26	33	43	41	46	41
Na	NA	3.7b	13a	3b	7a	7b	20a	6b	20a
H	23	14	7.9	57a	45b	28a	10b	22a	9b
Base saturation	77	86	92	43b	55a	72b	90a	78b	91a
ESP[1]	NA	3.7b	13a	3b	7a	7b	20a	6b	20a

[1]ESP = Exchangeable Na percentage

[2]NA = Not analyzed

Numbers followed by the same letter for a soil property within a sampling period are not significantly different at the 0.05 level of probability.

3.4. Plant Response to Irrigation

Biomass production: The cool-season bentgrass began growing earlier in the spring and initially produced higher biomass than the bermudagrass. The bentgrass, likely responding to the additional N (81 kg total N ha^{-1}) in the reclaimed water, produced higher leaf clipping mass with the reclaimed than the potable water during each of the monthly sampling periods (Figure 2). Clipping yields followed the order bermudagrass (potable) > bermudagrass (non-potable) > bentgrass (non-potable) > bentgrass (potable). The warm-season bermudagrass initially (May and June) produced greater biomass with the potable than the reclaimed water, but there were no differences between water sources for each of the monthly sampling periods from July through September (Figure 3).

Rooting: The extra N supplied by the reclaimed water appeared to have favored shoot growth over root growth in the immature (2.5 months old) bentgrass assessed in October 2004 (Figure 4). By April 2005, root growth of the bentgrass was the same regardless of water source. By August 2006, higher N and, possibly, higher Na in the reclaimed than the potable water reduced bentgrass root growth. Extra N in the reclaimed water did not affect bermudagrass root mass.

Tillering: Reclaimed water had no effect on bentgrass or bermudagrass tiller density throughout the study (data not shown).

Visual quality: Wear treatments resulted in more visual damage to the canopy of the bentgrass irrigated with the reclaimed than with the potable water in 2004 (Figure 5) but not in 2005. The irrigation source had no effect on bermudagrass aesthetics and wear recovery in 2004. Irrigation water source had no effect on wear recovery in 2005, when the quality of neither the potable nor the reclaimed water demonstrated an irrigation treatment advantage.

Nutrient assimilation: The N concentrations in the turfgrass species sampled weekly throughout 2005 were low (*i.e.*, <3%) in the spring, increased to greater than 3% during the summer, and plateaued at concentrations below their maxima from late summer to the end of the sampling period. Leaf tissue N concentration followed the order: bentgrass, non-potable (31.2 mg g^{-1}) > bentgrass, potable (28.1 mg g^{-1}) > bermudagrass, potable (26.4 mg g^{-1}) > bermudagrass, non-potable (24.9 mg g^{-1}). Turfgrass tissue P concentrations were considerably less predictable, ranging from 0.10% to 0.75%.

Total masses of N and P assimilated by the turfgrasses were calculated by multiplying the clipping nutrient concentrations by the total clipping dry weight. The bermudagrass assimilated considerably more N in its leaves, despite having lower tissue N concentrations, than did the bentgrass in 2005 (Table 3) because the bermudagrass produced significantly more dry matter than did the bentgrass between May and October (Figures 2 and 3). There was a turfgrass species x water source effect on N assimilation with the order of N uptake being: potable bermudagrass > reclaimed bermudagrass > reclaimed bentgrass > potable bentgrass (Table 3). The reclaimed water treatment increased P uptake of the bentgrass but not of the bermudagrass (Table 3).

Figure 2. Effects of irrigation water source and wear on clipping yield of ‘L-93’ creeping bentgrass in 2005. Wear was applied weekly in May, July, and September. Treatments by months with different letters are significantly different at 0.05 of probability.

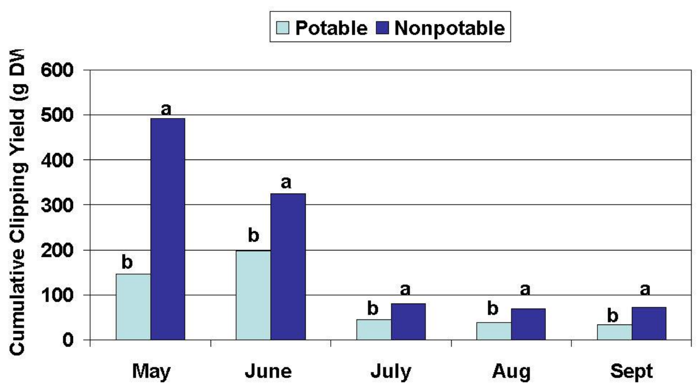


Figure 3. Effects of irrigation water source and wear on clipping yield of bermudagrass in 2005. Wear was applied weekly in May, July and September. Treatments by months with different letters are significantly different at 0.05 level of probability. NS = Not significant.

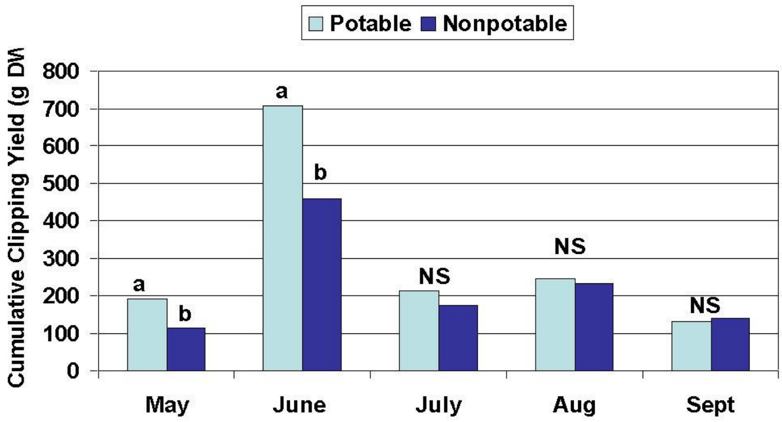


Figure 4. Effects of irrigation water source on root mass of bentgrass in 2004, 2005, and 2006. Root mass was higher (P < 0.05) with potable than reclaimed water in October 2004 and August 2006.

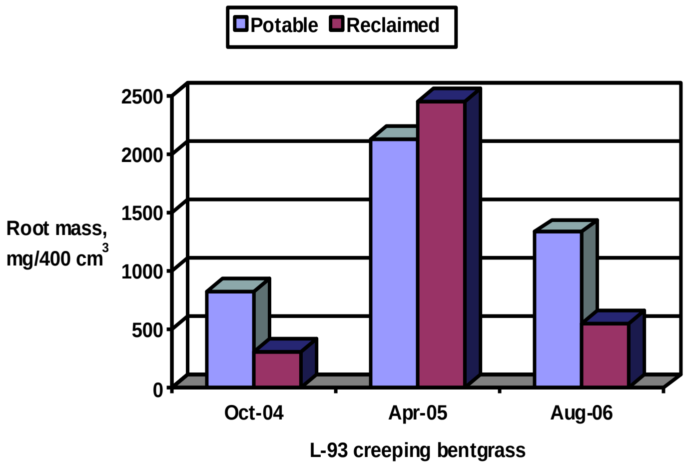


Figure 5. Effects of irrigation water source and wear on visual quality of 'L-93' creeping bentgrass in 2004. 9 = highest and 0 = lowest quality. Wear was applied weekly in July and September. Bars within each month followed by different letters are significantly different at 0.05 level of probability. NS = Not significant.

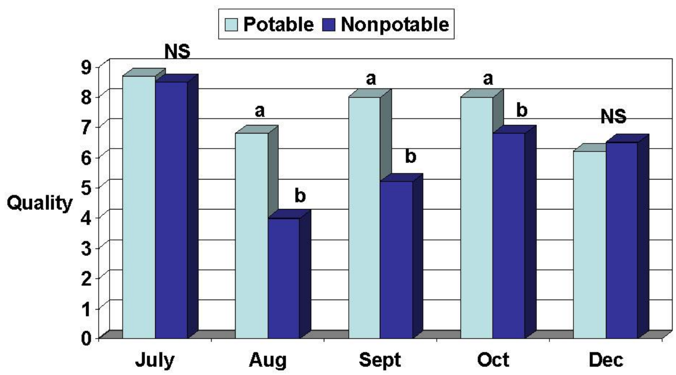


Table 3. Seasonal turfgrass N and P assimilation: May to October, 2005; May and July, 2006.

Water source treatment	2005		2006	
	Bentgrass	Bermudagrass	Bentgrass	Bermudagrass
	Leaf N uptake, kg N ha^{-1}			
Potable	112d	453a	45c	53b
Reclaimed	205c	335b	47c	61a
	Leaf P uptake, kg P ha^{-1}			
Potable	12c	44a	5.2ab	4.9b
Reclaimed	27b	41a	4.1c	5.3a

Numbers followed by the same letters within a plant tissue variable are not significantly different at the 0.05 level of probability.

Biomass production during May and July 2006 followed the same patterns as in 2005. Clipping production of the cool season bentgrass was higher in May and lower in July than the warm-season bermudagrass. Irrigation water source did not affect biomass production in May and July with bermudagrass (245 g sampling area^{-1}) producing significantly more biomass than bentgrass (150 g sampling area^{-1}) at the 0.05 probability level. As in 2005, bermudagrass assimilated more N than the bentgrass; however, the bermudagrass contained more N when irrigated with the reclaimed than with the potable water in 2006 (Table 3). Unlike 2005, there was no difference in bentgrass N uptake between water sources in 2006. There was a significant water source x turfgrass species interaction on leaf clipping P uptake with the potable water-irrigated bentgrass and the reclaimed water-irrigated bermudagrass assimilating the most P.

3.5. Leachate Water Quality

Nitrate N leachate concentrations in the bentgrass plots were never more than a few mg L^{-1} for either of the water treatments. The nitrate N leachate concentrations under the potable water-irrigated bermudagrass had decreased to nearly zero by late June and remained low until dormancy. The nitrate-N lost from the bermudagrass irrigated with reclaimed water was regularly above 10 mg L^{-1} and, on occasion, above 20 mg L^{-1} until early July. Ammonium N leachate concentrations followed the same order as for nitrate, *i.e.*, bentgrass > potable water-irrigated bermudagrass > reclaimed water-irrigated bermudagrass.

The concentrations of P in the leachate were affected more by the turfgrass species than by the irrigation water source. The reclaimed water-irrigated bermudagrass consistently had the highest and the reclaimed water-irrigated bentgrass consistently had the lowest total P concentrations in the lysimeter leachate.

There was no significant effect of treatment on the volume of leachate collected in the lysimeters during the monitoring period. The mean volume was 787 L m^{-2}. Neither turfgrass type nor irrigation source affected the masses of N and P leached (calculated as the product of leachate volume and nutrient concentration). The mean amounts of N and P lost via leaching during May to October 2005 were 21 kg N ha^{-1} and 3.4 kg P ha^{-1}.

4. Discussion

4.1. Irrigation Water Quality

Long term irrigation with water of the quality of the reclaimed may affect plant growth by the replacement of other plant essential cations (*i.e.*, Ca, Mg, and K) from the soil or reduce soil quality by increasing the sodium adsorption ratio (SAR) to the extent that soil structure may be compromised. Such an effect on sand media would not be expected. The concentrations of N and P in the reclaimed water will only pose a risk to groundwater if supplied at rates that significantly exceed the turfgrass assimilation capacity. The mean concentrations of N and P in the reclaimed water were lower than standards for reclaimed water in the Virginia Department of Environmental Quality Water Reclamation and Reuse Regulations for unrestricted irrigation use (http://www.deq.state.va.us/export/sites/default/vpa/pdf/Water_Reclamation_and_Reuse_Reg.pdf).

4.2. Soil Response

The potential detrimental effects of Na could be illustrated by the change in soil base (*i.e.*, Ca, Mg, K, and Na) saturation during the irrigation application period (Table 2). The cation exchange capacity of natural soils at agronomically sound pH levels (*i.e.*, 5.5 to 7) are typically dominated by Ca with lesser amounts of Mg and K, and the acid-forming cations, H and Al. Sodium is not commonly found in soils in the eastern humid region unless Na-containing amendments or irrigation are applied. As expected, Ca dominated the exchange capacity at the beginning of the study. The continued application of reclaimed water without addition of limestone resulted in the CEC being dominated by H (as pH decreased) and with a significant increase in the Na fraction of the CEC in the sand medium. The ESP values in the reclaimed water-irrigated soil increased with time and attained levels (*i.e.*, ESP = 20) that might be injurious by 2006. Commonly used criteria to identify coarse-textured soils, typically used in golf greens, that may exhibit detrimental effects on soil structure from high Na are ESP > 15. Recycled water as an irrigation source must account for the effluent SAR and EC together because salinity reduces the potential of Na to disperse soil particles [7].

4.3. Plant Response

Biomass production: We expected that the bermudagrass would have produced more biomass with the reclaimed than the potable water due to its high N assimilatory capacity, salt tolerance, and biomass production potential. Furthermore, bermudagrass is a more salt-tolerant species than bentgrass, which produced higher biomass with the reclaimed than the potable water treatment. We can only speculate that, despite its known salt tolerance, the bermudagrass may be particularly sensitive to salt upon breaking dormancy. Irrigation was initiated in 2005 after the bentgrass had begun growing and before the bermudagrass had broken dormancy.

Rooting: Such responses for cool-season bentgrass observed in October 2004 data support a classic response, *i.e.*, excess N favors shoot growth over root growth [15]. In bermudagrass, extra N rarely favors shoot over root growth. In fact, high rates of N applied to bermudagrass typically results in equal increases in root and shoot growth, *i.e.*, no preferential partitioning seems to occur [22]. Our data supported this classic observation.

Tillering: We had expected greater tiller density from the addition of higher N rates with the reclaimed water. It is possible that higher amounts of N than could be used for additional tillering were already supplied to the turfgrasses under the standard fertilization practices and potable water irrigation treatment and/or the "excess" amounts of Na and N provided with the reclaimed water may have had an antagonistic effect on tillering.

Visual quality: The higher N rate supplied with the reclaimed water likely caused more damage to the recently established bentgrass in 2004 because leaves with higher N contents are usually softer and thinner and wear faster than leaves with moderate N contents [23]. The ability of the bentgrass to recover from the wear treatments in 2005 with reclaimed water occurred after the turf was well-established.

4.4. Water Quality

The root system of the cool-season bentgrass remains live and functioning year-round under the mild climatic conditions of southeastern Virginia and is capable of assimilating considerable amounts of nitrogen early in the spring. The root system of the bermudagrass becomes dormant with fall frost, dies in late winter and does not begin to re-generate until the shoots have re-greened in the spring at soil temperatures of 13 °C and above. These rooting characteristics were reflected by the concentrations of NO_3-N and NH_4-N that accumulated in the lysimeters in May and June under the bentgrass and bermudagrass. Significantly higher concentrations of both of these forms of N were measured under the bermudagrass than under the bentgrass until late June when complete regeneration of the bermudagrass root system had occurred. Nitrate N continued to leach from the reclaimed water irrigated bermudagrass at higher concentrations than under the potable water-irrigated bermudagrass and either bentgrass irrigation source treatment until late July. Nitrate N concentrations under the bermudagrass reclaimed water irrigation treatment increased again by fall.

If the concentrations of N and P in the reclaimed water that leached through the soil were not affected by sorption to the sand medium or by plant uptake, the total amounts of N and P that should have been collected in the lysimeters would have been 57.5 kg N ha^{-1} and 3.31 kg P ha^{-1}. Comparison to the actual amount of N and P that leached through the medium indicated that the nutrient uptake by the turfgrass roots did not actively remove much P from the percolating water; however, 63% of the N in the reclaimed water was not transported to the lysimeter. This supports active uptake of N by the turfgrass species with a resulting reduction in the concentration of N in the irrigation water.

5. Conclusions

Even in the humid eastern U.S., irrigation with reclaimed water high in Na can result in an imbalance of cations on the soil exchange complex. Such Na accumulation may eventually impair soil permeability if not replaced by amending the medium with soluble forms of calcium.

High salt content of reclaimed water without further processing was adequate for supporting the production of high quality turfgrass in the short term; however, continual use of reclaimed of such quality may eventually impair the quality of turfgrass, especially that recently established. The unexplained cause of the reduction of clipping yield of bermudagrass in early 2005 may be associated with deleterious effects of high salt- or Na-containing irrigation water on the growth of the warm season grass upon breaking of dormancy. Applying high amounts of N with reclaimed water to an establishing bentgrass may produce aboveground growth at the expense of development of a strong root system. In both these cases, it may be advantageous to irrigate a recently established or dormant turfgrass with potable water before switching to a higher salt-containing reclaimed water source.

The high nutrient assimilation capacity of bermudagrass and bentgrass prevented leaching of N and P where reclaimed water meeting biological nutrient removal standards was used. The turfgrasses were able to selectively remove N from the irrigation water, thus reducing the N concentration in the percolate that leached below the root zone. Furthermore, these results were achieved using very high irrigation rates. Typical water reuse practices recommend a 10% leaching fraction to prevent excessive soluble salt accumulation in the soil profile. Irrigation of effluent with low nutrient concentrations due to biological nutrient removal processes will not impair groundwater quality under a wide range of normal watering practices.

Acknowledgements

This study was funded by the Hampton Roads Sanitation District (HRSD), Virginia. We wish to thank Stan Stagg of Staggwood Greens, Inc for his establishment and maintenance of the plots, collection of rainfall and irrigation data, and mowing for clipping biomass determination; George Kennedy of HRSD for providing the analysis of the reclaimed water used in the study; Tom Serensits of the Virginia Tech Hampton Roads Agriculture and Education Center for collection and processing of lysimeter water samples and grass clippings; Beshr Sukkariyah for soil, water and plant analysis and calculation of statistics and preparation of figures; and Kathryn Haering for assistance with the manuscript editing.

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