Published May, 2010

RESEARCH

Effects of Sod Type, Irrigation, and Fertilization on Nitrate-Nitrogen and Orthophosphate-Phosphorus Leaching from Newly Established St. Augustinegrass Sod

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ABSTRACT

Nitrogen and P leaching losses from fertilized turfgrass remain an environmental concern. In the present study, we examined the effects of sod type, fertilization, and irrigation on turf quality, NO_3–N and PO_4–P leaching following St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] sod installation. Treatments included muck- vs. sand-produced sod, no fertilization, fertilization with 4.9 g N m^{-2} at installation or at 30 d after installation (DAI), and routine irrigation or irrigation at stress from 30 to 60 DAI. Drainage was collected from lysimeters installed in each plot and analyzed for NO_3–N and PO_4–P to determine total leaching losses. Across all treatments, drainage averaged 290, 902, and 604 mm during each of the three trials. Fertilization at 30 DAI significantly reduced PO_4–P leaching losses compared to fertilization at 0 DAI. Muck sod type significantly reduced the quantity of NO_3–N leached. Muck sod also significantly reduced PO_4–P leached and resulted in better turf quality in two of the three trials. In the context of minimizing nutrient leaching, these results support the use of muck-grown sod established during low rainfall periods with fertilization delayed at least 30 DAI and with judicious use of irrigation.

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Abbreviations: BMP, best management practice; DAI, days after installation; MDL, minimum detection limit.

Blended fertilizers containing both N and P are frequently used on residential landscapes to maintain turfgrass growth and quality. Leaching losses of applied N and P pose a significant environmental threat (Vitousek et al., 1997; Carpenter et al., 1998; Noe et al., 2001; Tilman et al., 2002). Consequently, much attention has been focused on best management practices (BMP's) for turfgrass. In particular, recent studies have indicated the magnitude and relative importance of nutrient losses during establishment (Erickson et al., 2001; Bowman et al., 2002; Hay et al., 2007; Barton et al., 2009) for which information on management practices are much more poorly defined and data on leaching losses are much more scarce compared to established stands. In Florida, for example, the sod industry produces more than 40,000 ha of turfgrass on various soil types (Satterthwaite et al., 2009), but we lack data on how soil type affects nutrient leaching following sod installation.

In addition to effects on growth and quality, turfgrass cultural practices are known to impact nutrient leaching losses (Starr and DeRoo, 1981; Petrovic, 1990; Soldat and Petrovic, 2008). In particular, numerous studies have examined the effects of fertilization and irrigation on nutrient leaching losses from turfgrass. These studies

Published in Crop Sci. 50:1030–1036 (2010).
doi: 10.2135/cropsci2009.07.0411
Published online 10 Mar. 2010.

Table 1. Chemical properties of the root-zone substrate used in the study (n = 2).

Property	
pH	6.9
Organic matter, %	0.2
Weak Bray P, mg L^{-1}	6 VL†
Strong Bray P, mg L^{-1}	8.5 VL
K, mg L^{-1}	3 VL
Ca, mg L^{-1}	600 VH
Mg, mg L^{-1}	8.5 VL

†VL, very low; VH, very high.

have found that nutrient leaching losses, especially NO_3–N, tend to increase with increased rate of fertilization and with reduced frequency of fertilizer application (Reike and Ellis, 1974; Petrovic, 1990; Barton et al., 2006; Soldat and Petrovic, 2008). Soluble fertilizer sources tend to increase leaching losses, while slow-release and/or organic sources of N have been shown to reduce leaching from turfgrass (Snyder et al., 1980; Shuman, 2001; Easton and Petrovic, 2004). Abundant irrigation and/or precipitation has been shown to greatly increase nutrient leaching, especially on sandy soils (Snyder et al., 1984; Morton et al., 1988; Petrovic, 2004; Erickson et al., 2005). As a result of these findings, fertilization and irrigation BMP's have been implemented, which have generally resulted in minimal nutrient leaching from established turfgrass stands (Bowman et al., 2002; Erickson et al., 2008; Soldat and Petrovic, 2008). Although not as extensively studied as fertilization and irrigation, establishment practices have also been shown to affect nutrient leaching losses from turf. For example, Hay et al. (2007) showed 10 times greater leaching loss of NO_3–N from sprigged 'Tifway' bermudagrass compared to sod from 0 to 50 d after planting and no difference between fertilizer- or manure-grown sod.

Turf establishment from sod is the most efficient establishment method with regard to minimizing nutrient leaching during establishment. However, little information is available regarding nutrient losses following sod establishment from sod produced on differing soil types. In Florida, St. Augustinegrass is the primary turfgrass used for home lawns, and is most commonly established from sod. It is primarily produced on Histosols, which are characterized by high organic matter content and commonly referred to as muck soils, and on Spodosols, which are characterized by fine sand with a spodic horizon beginning at 20 to 50 cm. Recent trends in south Florida sod production indicate a shift away from muck soils to sand, mainly due to market proximity (Satterthwaite et al., 2009). There are several notable differences between these soil types that could affect nutrient leaching during establishment. Muck soils are typically higher in N (Porter and Sanchez, 1994), so N mineralization can be relatively high. Organic P is also relatively high in muck soils and can provide available P when mineralized (Cisar et al., 1992). Muck soils also have a much higher water holding capacity than fine sandy soils. The sandy soils are low in organic matter in the A horizon, have a low cation exchange capacity (<5cmol$_c$ kg^{-1}) with virtually no sorption capacity for inorganic P (Fox et al., 1990).

Given that little data on nutrient leaching following sod installation exists under any management scenario, the objectives of the current study were to evaluate the effects of establishment, fertilization, and irrigation on NO_3–N and orthophosphate-P leaching and turf quality and growth for 2 mo following installation of St. Augustinegrass sod under field conditions. Specifically, we wanted to test (i) whether sod produced on muck soils would differ in nutrient leaching following installation compared to sod produced on a sandy soil; (ii) whether fertilization at 30 DAI compared to fertilization at installation could reduce nutrient leaching without adverse effects on quality; and (iii) whether irrigation at visual wilt (i.e., at first sign of leaf rolling) 30 to 60 DAI compared to routine irrigation every other day could reduce nutrient leaching without adverse effects on quality.

MATERIALS AND METHODS

Experimental Site and Design

The study was conducted at the University of Florida's Research and Education Center in Fort Lauderdale, FL (26°03′ N, 80°13′ W). The climate is subtropical allowing for turfgrass growth year round, with a mean wet season temperature of 26.8°C and a mean dry season temperature of 21.9°C (National Climatic Data Center, Asheville, NC). Rainfall (1971–2000) measured at Fort Lauderdale (approximately 5 km from the site) averages 1631 mm per year. Plots containing lysimeters were established on an underlying fill foundation using a mined fine (62.9%) sand that closely matched the native fine (68.7%) sand that was low in organic matter, P, and K (Table 1).

The experiment consisted of 36 plots in a split-plot randomized complete block design. Sod type (2), irrigation (2), and fertilization (3) were the three factors included in the experiment. Eighteen main irrigation and fertilization plots (4 by 4 m) were split in half (4 by 2 m) with each half containing a sod produced on either muck or mineral soil (n = 3). The sod was St. Augustinegrass (cultivar 'Floratam') produced in south Florida on either a highly decomposed organic soil (Histosol) or a fine sand mineral soil (Spodosol). The three fertilization treatments were (i) no fertilizer, (ii) 4.9 g N m^{-2} of 6–6–6 (2.35% ammoniacal-N and 3.65% urea-N; United Industries Corp., St. Louis, MO) at trial initiation (0 DAI), and 3) 4.9 g N m^{-2} of 6–6–6 at 30 DAI (Cisar et al., 1991). Irrigation treatments included (i) 6.4 mm twice daily for 30 d, then 12.7 mm every other day (approximate reference ET) for 30 d and (ii) 6.4 mm twice daily for 30 d, then 12.7 mm at sign of visual wilt for 30 d using overhead perimeter irrigation.

At the onset of each trial, recently cut sod was installed in each of the lysimeters. Sod produced on muck soil for trials 1and 2 was received from King Ranch (Belle Glade, FL). Soil analysis from the site showed 81.2% organic matter, 0.6% total N, and 0.06% total P. Sod from muck soil and for trial 3 was received from TJ Turf Farm (Delray Beach, FL), and was lower in organic matter, 58.5%, total N, 0.2%, and total P, 0.02%. Sod produced on sandy mineral soil was received from A. Duda and Sons (La Belle, FL). Soil analysis from the site showed 2.6% organic matter, 0.2% total N, and 0.01% total P. All soil analyses were conducted by A and L Southern Agricultural Laboratories, Inc. (Pompano Beach, FL).

Data collection for each trial lasted approximately 60 d; turf from each plot was then removed and plots left fallow for about 60 d. The experiment was repeated three times and new sod was installed at the beginning of each of three trials. The root-zone mix was tested for N and P at the end of the trials and did not show any significant carryover effects from previous trials, nor did it differ from the data presented in Table 1. A pretrial fertilization of micronutrients (Cl: 2%; Mg: 9.4%; Mn: 3.0%; Cu: 0.2%; Zn: 0.7%; Fe: 6.25%; Major Minors no. 1070, AFEC, Homestead, FL) was applied to and incorporated into the soil at a rate of 98 g m^{-2} per plot. Additionally, triple superphosphate (0–46–0) was incorporated into the soil at 2.44 g m^{-2} before each of the trials began.

Measures of Turfgrass Quality and Growth

Turfgrass visual quality was assessed at the end of each 2 mo period using a 1 to 10 scale (10 = dark green turf, 1 = dead/brown turf, and 6 = minimally acceptable turf). Shoot growth of each plot was measured by collection of the dry matter of clippings produced throughout each 2-mo growth period. Clipping samples were collected routinely throughout the trials, as the turf was maintained at a 7.5 cm height of cut. Clipping dry weights were obtained after clippings were oven dried at 60°C to a constant weight. Root samples were taken from each plot (no data available for the first trial) by removing 10.2 cm diam. cup cutter cores at two depths: 0 to 15 cm and 15 to 30 cm. Root samples were washed and oven-dried to a constant mass at 60°C and then weighed. Samples were then ashed in a muffle furnace (550°C) and reweighed. Root weights are presented as oven dry weight minus ash weight, minimizing potential error from residual sand on washed roots. Root weights were pooled together to give standing root biomass in the upper 30 cm of soil.

Measures of Drainage and Nutrient Leaching

Drainage was measured using lysimeters inserted in each of the plots. The lysimeters were constructed from 208 L (92 cm height; 59.7 cm diam.; 1.3 cm thick wall) polyethylene drums with a flat bottom (U.S. Plastic Corp., Lima, OH). Lysimeters were fitted with a 1.9 cm PVC drainage pipe at the bottom to collect drainage. Each lysimeter was then filled with approximately 10 cm of 0.6 cm river gravel, a 5 cm layer of coarse sand and then filled with the fine sand root-zone mix to the same level as the rest of the surrounding plot. Drainage water from each lysimeter was collected in 19 L polyethylene containers.

Percolate water samples were taken twice weekly and more frequently when a rain event occurred and were immediately fixed with acid on collection and refrigerated according to Florida Department of Environmental Protection protocol. Percolate samples were analyzed by colorimetric methods for NO_3–N (USEPA Method 353.2; minimum detection limit [MDL] = 0.1 mg L^{-1}) and orthophosphate-P (USEPA Method 365.1; MDL = 2 μg L^{-1}) by the University of Florida Analytical Research Laboratory (Gainesville, FL). Values below the MDL were reported at half the MDL. Flow-weighted mean concentrations (total quantity leached/total volume percolate) and total quantity of nutrient leached were determined from laboratory analyses and volume of drainage for each of the three 60 d trials.

Analysis of Data

Data were analyzed across all three trials and trial was treated as a fixed effect. Significant treatment effects and their interactions were identified by analysis of variance using the generalized mixed-model procedure (GLIMMIX) of the SAS system (Littell et al., 2006). Each treatment was replicated three times. Degrees of freedom were determined using the Kenward-Roger method. Residuals from each model fit were analyzed for normality both graphically and numerically with the Shapiro-Wilk W test. Data were also checked graphically for homogeneity of variance. Where necessary, response data were transformed using a square root transformation and analysis of variance was conducted on the transformed data, which satisfied assumptions of normality and homogeneity of variance when needed. Due to multiple significant interactions between trial and other treatments, mean treatment values on untransformed data are presented for each trial separately.

RESULTS

Climate and Hydrology during Each Trial

Average daily air temperature was 24.8, 25.9, and 25.7°C during trials 1 (29 Mar. 2005–25 May 2005), 2 (14 Sept. 2005–14 Nov. 2005) and 3 (28 Mar. 2006–31 May 2006), respectively. Trial 1 was the driest of the three 2-mo data collection intervals, receiving 109 mm of rainfall, which occurred over seven separate rain events. In contrast, trial 2 occurred during the wet season and 436 mm of rainfall was received in 21 separate daily rain events. Drainage was significantly ($P < 0.01$) affected by trial (Table 2), and was lowest during trial 1, averaging about 238 mm across all treatments and highest during trial 2, averaging 740 mm. Significantly lower drainage was associated with fertilization, especially fertilization at 30 DAI (Table 2). As expected, we observed a significant reduction in drainage, approximately 10%, with less water input when irrigation was applied at visual wilt.

Nutrient Leaching

Quantity of NO_3–N leached was significantly affected by trial (Table 2) and followed patterns of drainage, averaging 6.8 ± 1.0 kg ha^{-1}, 15.3 ± 2.4 kg ha^{-1}, and 11.6 ± 2.4 kg ha^{-1} during trials 1 (Table 3), 2 (Table 4), and 3 (Table 5), respectively. Flow-weighted [NO_3–N] did not differ significantly with trial ($P > 0.05$), however, averaging 8.5 ± 0.8 mg L^{-1} across all trials and treatments. The muck sod type significantly reduced both flow-weighted [NO_3–N] and the quantity of NO_3–N leached (Table 2). In addition, there was a significant sod type × fertilization interaction on flow-weighted [NO_3–N], whereby significantly lower flow-weighted [NO_3–N] was found for the muck sod compared to the sand-produced sod when fertilized at 30 DAI. Although, no significant ($P = 0.10$) fertilization effect on N leaching was observed in the study, we did see a trend toward increased NO_3–N leaching losses when fertilized at 0 DAI (Tables 3, 4, and 5).

Table 2. Analysis of variance results for drainage (L), quantity of NO_3–N leached (kg ha^{-1}), flow-weighted concentration of NO_3–N (mg L^{-1}), quantity of PO_4–P leached (kg ha^{-1}), flow-weighted concentration of PO_4–P (mg L^{-1}), turf quality at the end of the trial, dry weight (DW; kg ha^{-1}) of clippings produced during each trial, and DW (kg ha^{-1}) of roots produced in the upper 30 cm.

Effect	Drainage	NO_3–N leached	NO_3–N	PO_4–P leached	PO_4–P	Quality	Clipping DW	Root DW
Sod type	ns†	*	**	ns	ns	**	**	ns
Fertilization (Fert)	*	ns	ns	*	**	**	**	ns
Irrigation (Irrig)	*	ns	ns	ns	ns	ns	ns	ns
Trial	**	**	ns	**	*	**	**	**
Sod × Fert	ns	ns	*	ns	ns	ns	ns	ns
Sod × Irrig	ns	ns	ns	*	**	ns	ns	ns
Trial × Sod	ns	ns	*	*	*	**	**	ns
Trial × Fert	ns	ns	ns	ns	**	**	**	ns
Trial × Irrig	ns	ns	ns	**	**	ns	ns	ns
Sod × Fert × Irrig	**	ns	ns	*	ns	ns	ns	ns
Trial × Fert × Irrig	ns	ns	ns	ns	**	ns	ns	ns

* $P < 0.05$.

** $P < 0.01$.

†ns, not significant ($P > 0.05$). Note: Interactions not shown were not significant.

Quantity of PO_4–P leached was significantly affected by trial (Table 2), averaging 1.5 ± 0.3 kg ha^{-1}, 4.0 ± 0.3 kg ha^{-1}, and 3.0 ± 0.3 kg ha^{-1} during trials 1 (Table 3), 2 (Table 4), and 3 (Table 5), respectively. While quantity of PO_4–P leached followed patterns of drainage (i.e., less during the dry season trials), flow-weighted [PO_4–P] also differed significantly across trials (Table 2). In contrast to N, sod type did not significantly affect P leaching across all treatments and trials. Both PO_4–P leached and flow-weighted [PO_4–P] were significantly affected by fertilization in a similar manner. Fertilization at 30 DAI significantly reduced P leaching compared to fertilization at 0 DAI, and both of these treatments did not differ significantly from the treatment that received no fertilizer. A significant sod × trial interaction indicated reduced P losses from the muck sod type with the exception of trial 1, where the sod types did not differ. In addition, a significant trial × irrigation interaction (Table 2) indicated that trial 1 was the only trial to show any significant difference between irrigation treatments, with irrigation at visual wilt showing less PO_4–P losses, while irrigation had no effect in the wetter trials 2 and 3.

Turfgrass Growth and Quality

Turf quality averaged 6.8 ± 0.2, 6.4 ± 0.2, 6.4 ± 0.2 during trials 1 (Table 3), 2 (Table 4), and 3 (Table 5), respectively. Clipping dry weights averaged 235 ± 34 kg ha^{-1}, 261 ± 30 kg ha^{-1}, and 292 ± 23 kg ha^{-1} during trials 1, 2, and 3, respectively. Across all trials, we observed significantly greater quality on the muck sod (6.9) compared to the sand sod (6.0). Similarly, significantly greater clipping quantities were seen on the muck sod. Fertilization affected turf quality at the end of the study as expected; fertilization at 30 DAI showed significantly better quality (7.4) than fertilization at 0 DAI (6.3), which was significantly better than no fertilization (5.8). Clipping quantities did not

Table 3. Trial 1 treatment means (n = 3) for drainage (mm), quantity of NO_3–N leached (kg ha^{-1}), flow-weighted concentration of NO_3–N (mg L^{-1}), quantity of PO_4–P leached (kg ha^{-1}), flow-weighted concentration of PO_4–P (mg L^{-1}), turf quality at the end of the trial, and dry weight (DW; kg ha^{-1}) of clippings produced during the trial. Root DW not available (na). Fertilization treatments were no fertilizer (1), 4.9 g N m^{-2} at 0 d after installation (2), and 4.9 g N m^{-2} at 30 d after installation (3). Irrigation treatments were 6.4 mm twice daily for 30 d, then 12.7 mm every other day (1) or 12.7 mm at sign of visual wilt (2) for the next 30 d.

Sod type	Fertilization	Irrigation	Drainage	NO_3–N leached	NO_3–N	PO_4–P leached	PO_4–P	Quality	Clipping DW	Root DW
Muck	1	1	354	9.64	10.4	4.12	4.34	6.83	456	na
		2	220	4.39	7.14	0.57	0.90	7.16	395	na
	2	1	174	4.66	9.34	0.79	1.79	7.17	420	na
		2	276	13.4	18.9	2.88	4.00	7.00	487	na
	3	1	217	6.30	8.50	0.93	1.06	8.33	470	na
		2	185	3.49	6.40	0.18	0.40	8.00	356	na
Sand	1	1	237	2.83	3.90	2.45	4.72	5.17	65.0	na
		2	194	5.59	7.34	0.05	0.34	5.33	33.3	na
	2	1	375	14.0	13.2	4.45	4.12	5.67	55.3	na
		2	157	7.42	12.5	1.22	2.07	6.00	60.0	na
	3	1	291	5.47	7.25	0.27	0.27	7.67	57.7	na
		2	195	7.08	11.8	0.13	0.23	6.83	40.0	na

Table 4. Trial 2 treatment means (n = 3) for drainage (mm), quantity of NO_3–N leached (kg ha^{-1}), flow-weighted concentration of NO_3–N (mg L^{-1}), quantity of PO_4–P leached (mg m^{-2}), flow-weighted concentration of PO_4–P (mg L^{-1}), quality at the end of the trial, dry weight (DW; kg ha^{-1}) of clippings produced during the trial, and DW (kg ha^{-1}) of roots produced in the upper 30 cm. Fertilization treatments were no fertilizer (1), 4.9 g N m^{-2} at 0 d after installation (2), and 4.9 g N m^{-2} at 30 d after installation (3). Irrigation treatments were 6.4 mm twice daily for 30 d, then 12.7 mm every other day (1) or 12.7 mm at sign of visual wilt (2) for the next 30 d.

Sod type	Fertilization	Irrigation	Drainage	NO_3–N leached	NO_3–N	PO_4–P leached	PO_4–P	Quality	Clipping DW	Root DW
Muck	1	1	843	4.92	2.18	3.56	1.51	6.50	238	925
		2	704	9.99	5.11	3.76	1.85	6.65	271	999
	2	1	761	24.7	11.4	4.21	1.97	7.83	586	1200
		2	736	25.6	12.9	5.38	2.69	7.00	532	1210
	3	1	689	9.13	4.47	1.74	0.91	7.50	359	1260
		2	757	9.58	4.48	2.89	1.35	7.17	332	876
Sand	1	1	764	3.16	1.50	3.93	1.83	5.17	109	1390
		2	750	6.37	3.02	3.55	1.70	5.50	68.5	1230
	2	1	632	38.4	17.8	6.16	2.78	6.17	185	1180
		2	679	18.7	9.91	5.68	2.94	5.33	92.6	1170
	3	1	707	27.0	14.1	4.20	2.10	5.67	144	1410
		2	729	14.2	6.72	3.61	1.81	5.83	192	1370

differ between fertilization at 0 or 30 DAI, but both were significantly greater than the unfertilized control. Both quality and clipping yields showed a significant trial × sod interaction, whereby we observed better quality and clipping yields from the muck sod type during trials 1 and 2, but the sand sod performed better in trial 3.

Finally, root dry weights in the upper 30 cm were significantly affected by trial, averaging 1184 ± 62 kg ha^{-1} and 1502 ± 61 kg ha^{-1} during trials 2 and 3, respectively. However, root dry weights were not significantly affected by any of the other treatments (Table 2).

DISCUSSION

Treatment Effects on Nutrient Leaching

The primary objective of the current study was to evaluate the effects of management practices on nutrient leaching during establishment of St. Augustinegrass sod on a sandy soil. We tested the effects of sod type (sod produced on sand vs. muck soils), fertilization, and irrigation on NO_3–N and PO_4–P leaching losses. Both NO_3–N and PO_4–P nutrient leaching losses were strongly correlated with precipitation and drainage as evidenced by the significant trial effects and high leaching losses during the wetter trials. Beyond trial effects, however, sod type was the primary factor affecting NO_3–N leaching and flow-weighted (NO_3–N), with reduced losses found on the muck-produced sod. In contrast, PO_4–P leached and flow-weighted (PO_4–P) were primarily affected by fertilization. However, less PO_4–P leaching losses were also generally observed from the muck sod type, except during trial 1, the driest of the three trials.

Nitrate-N leaching losses ranged from <0.1 to 27.0 kg ha^{-1} or from <0.2% to more than 50% of postinstallation applied

Table 5. Trial 3 treatment means (n = 3) and analysis of variance results for drainage (mm), quantity of NO_3–N leached (kg ha^{-1}), flow-weighted concentration of NO_3–N (mg L^{-1}), quantity of PO_4–P leached (mg m^{-2}), flow-weighted concentration of PO_4–P (mg L^{-1}), quality at the end of the trial, dry weight (DW; kg ha^{-1}) of clippings produced during the trial, and DW (kg ha^{-1}) of roots produced in the upper 30 cm. Fertilization treatments were no fertilizer (1), 4.9 g N m^{-2} at 0 d after installation (2), and 4.9 g N m^{-2} at 30 d after installation (3). Irrigation treatments were 6.4 mm twice daily for 30 d, then 12.7 mm every other day (1) or 12.7 mm at sign of visual wilt (2) for the next 30 d.

Sod type	Fertilization	Irrigation	Drainage	NO_3–N leached	NO_3–N	PO_4–P leached	PO_4–P	Quality	Clipping DW	Root DW
Muck	1	1	586	12.1	7.59	2.48	1.52	5.33	162	1370
		2	479	0.46	0.36	2.14	1.65	5.06	75.3	1330
	2	1	547	12.5	8.16	2.45	1.60	6.33	145	1790
		2	461	22.4	17.8	4.15	3.11	5.83	171	1550
	3	1	454	0.14	0.10	1.11	0.96	7.67	211	1970
		2	486	0.20	0.15	2.01	1.44	7.67	170	1340
Sand	1	1	514	19.2	12.9	4.14	2.84	5.50	286	1090
		2	568	10.8	6.99	5.05	3.03	5.17	256	1520
	2	1	511	24.4	19.2	5.32	3.35	6.50	476	1360
		2	461	13.4	11.0	3.04	2.41	5.17	442	1480
	3	1	414	11.5	9.95	1.94	1.68	8.33	500	1390
		2	447	8.57	6.91	2.37	1.87	7.67	608	1800

fertilizer N, and flow-weighted (NO_3–N) averaged about 8.5 mg L^{-1} across all treatments, just below the 10 mg L^{-1} drinking water standard established by the U.S. Environmental Protection Agency. Erickson et al. (2001) and Bowman et al. (2002) report NO_3–N leaching between 1 and 3% on newly established St. Augustinegrass, but in both these studies data were not collected immediately after sod installation and were not subject to intense precipitation, as occurred during trial 2 in the current study. Intense precipitation in trial 2 resulted in significantly greater NO_3–N leaching losses compared to the other two trials. This is consistent with other studies that have indicated the importance of rainfall/irrigation inputs on NO_3–N leaching (Snyder et al., 1984; Morton et al., 1988; Barton et al., 2006; Erickson et al., 2008).

Our results showed that on average across all treatments the quantity of NO_3–N leached from sand-produced sod was about 30% greater following establishment compared to muck produced sod. While other studies have shown significant reductions in NO_3–N leaching for sod vs. sprigged turf (e.g., Hay et al., 2007), we believe this is one of the first studies to show the potential importance of muck derived sod compared to mineral soil produced sod. This main effect was significant across all treatments, but was especially prominent when fertilized at 30 DAI as this was when the muck sod reduced NO_3–N leaching the most compared to the sand sod.

Averaged across all three trials, NO_3–N leaching was the same from the unfertilized treatment and the 30 DAI treatment (approximately 8.0 kg ha^{-1}), whereas fertilization at installation doubled NO_3–N lost (17 kg ha^{-1}). The similarity in NO_3–N leaching from the unfertilized treatment and fertilization at 30 DAI coupled with significant differences in quality and growth suggests that addition of fertilizer N at 30 DAI resulted in no further NO_3–N leaching losses. In other words, the grass was well established by 30 DAI and NO_3–N leaching losses were minimal as commonly reported for St. Augustinegrass (Bowman et al., 2002; Erickson et al., 2008).

Across all trials and treatments PO_4–P leached averaged 2.8 kg PO_4–P ha^{-1} during the 2-mo establishment periods, which was about 13% of what was applied to the fertilized treatments. Erickson et al. (2005) reported similar PO_4–P losses of 0.25 g P m^{-2} 2 mo^{-1} on St. Augustinegrass sod that had been installed ~45 d before data collection. In a comprehensive review on P leaching losses from mineral soils, Soldat and Petrovic (2008) reported annual leaching losses of PO_4–P in the range of 0.02 to 0.07 g m^{-2} for established turfgrass on finer-textured soils. Like NO_3–N leaching losses, PO_4–P leached was closely correlated with water inputs and drainage in the study, as significantly greater losses occurred during trial 2 in the wet season. This supports a growing body of literature showing the mobility of PO_4–P in soils with low capacity for P sorption and the potential for significant PO_4–P losses from turfgrass (Erickson et al., 2005; Soldat and Petrovic, 2008). In addition, a number of significant interactions with irrigation were seen, such as a significant reduction in PO_4–P leaching with reduced irrigation during the driest trial (1) compared to no irrigation effect during the wettest trial (2), likely due to the decreased importance of irrigation when rainfall is abundant.

Fertilization at 30 DAI significantly reduced both quantity of PO_4–P leached and flow- weighted (PO_4–P) compared to fertilization at 0 DAI, and was no different than the unfertilized control. A significant sod × trial interaction further showed that PO_4–P leaching was reduced on the muck sod in trials 2 and 3 compared to the sand sod, while in trial 1 no difference in PO_4–P leaching was seen on the sand sod, likely due to low precipitation and drainage. This greater PO_4–P leaching from the sand sod could reflect reduced ability of sand sod to retain applied P and/or possibly higher P application rates generally used on sand soils vs. muck soils for production (Cisar et al., 2009).

Turfgrass Performance

Improved turf quality with N fertilization is well documented (Starr and DeRoo, 1981; Petrovic, 1990) and in the current study fertilization consistently improved turf quality at the end of the 2-mo establishment period across all trials. Fertilization at 30 DAI tended to produce the best quality at the end of the study, likely the result of proximity to fertilization combined with improved efficiency of fertilizer N uptake associated with better root development. This finding was consistent with the greater NO_3–N leaching observed with fertilization at 0 DAI compared to 30 DAI as discussed above. The muck sod was also associated with better quality scores except for trial 3 when it did not perform as well. Expectedly, effects of irrigation were seen only in the dry season trials when rainfall was less abundant (Jordan et al., 2003), whereby irrigation at visual wilt tended to result in modestly lower quality scores.

Higher turf quality observed on the muck sod was generally correlated with increased clipping production, with the exception of trial 3 where greater clipping dry weights were observed on the sand sod treatment. Since fertilizer and irrigation treatments were the same in each of the trials, this variation in clipping dry weights associated with sod type was most likely due to producer or location on the producer's farm. The muck sod used in trial 3 contained about 20% less organic matter and showed lower initial quality compared to trials 1 and 2, whereas the sand sod used in trial 3 had a higher initial quality score (7.0) compared to trials 1 and 2 (5.9). Clipping yields and root growth were affected by sod type, and were generally inversely related to nutrient leaching (i.e., increased clipping yields were associated with reduced NO_3–N and PO_4–P leaching).

CONCLUSIONS

While results from the current study were variable across trials, reflecting the effects of seasonality as well as production practices, some general conclusions regarding management practices during sod installation were also evident. First, fertilization at installation was unnecessary in that turf quality was no better at 60 DAI and it also resulted in significantly greater orthophosphate-P leaching and a trend toward greater NO_3–N leaching losses, especially when coupled with abundant precipitation during the wet season. Second, sod installation when rainfall is frequent and abundant resulted in increased nutrient leaching losses and should be avoided if possible. By extension, judicious irrigation during establishment should also be used. Finally, muck produced sod generally resulted in better quality turf with reduced NO_3–N and orthophosphate-P leaching during establishment compared to sand produced sod, although this seemed to depend on initial quality of sod (e.g., carryover effect from sod production practices) and management practices. Further research is needed on refining management practices for sod installation.

Acknowledgments

This work was supported by The Florida Department of Environmental Protection. We are grateful to Karen Williams and Eva Greene for assistance with maintenance and sample collection.

References

Barton, L., G.G.Y. Wan, R.P. Buck, and T.D. Colmer. 2009. Does N fertilizer regime influence N leaching and quality of different-aged turfgrass (*Pennisetum clandestinum*) stands. Plant Soil 316:81–96.

Barton, L., G.G.Y. Wan, and T.D. Colmer. 2006. Turfgrass (*Cynodon dactylon* L.) sod production on sandy soils: II. Effects of irrigation and fertilizer regimes on N leaching. Plant Soil 284:147–164.

Bowman, D.C., C.T. Cherney, and T.W. Rufty, Jr. 2002. Fate and transport of nitrogen applied to six warm-season turfgrasses. Crop Sci. 42:833–841.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol. Appl. 8:559–568.

Cisar, J.L., P.C. Mc Groary, and G.H. Snyder. 2009. Nutrient study for sod production in Lake Okeechobee watershed. Task 1. Sod farm phosphorus use study. South Florida Water Manage. District Rep., West Palm Beach, FL.

Cisar, J.L., G.H. Snyder, and P. Nkedi-Kizza. 1991. Maintaining quality turfgrass with minimal nitrogen leaching. Inst. of Food and Agric. Sci. Bull. 273. Univ. of Florida, Gainesville.

Cisar, J.L., G.H. Snyder, and G.S. Swanson. 1992. Nitrogen, phosphorus, and potassium fertilization for Histosol-grown St. Augustinegrass sod. Agron. J. 84:475–479.

Easton, Z.M., and A.M. Petrovic. 2004. Fertilizer source effect on ground and surface water quality in drainage from turfgrass. J. Environ. Qual. 33:645–655.

Erickson, J.E., J.L. Cisar, G.H. Snyder, D.M. Park, and K.E. Williams. 2008. Does a mixed-species landscape reduce inorganic-N leaching following establishment compared to a conventional St. Augustinegrass lawn? Crop Sci. 48:1586–1594.

Erickson, J.E., J.L. Cisar, J.C. Volin, and G.H. Snyder. 2001. Comparing nitrogen runoff and leaching between newly established St. Augustinegrass turf and an alternative residential landscape. Crop Sci. 41:1889–1895.

Erickson, J.E., J.L. Cisar, J.C. Volin, G.H. Snyder, and D.M. Park. 2005. Phosphorus and potassium leaching under contrasting residential landscape models established on a sandy soil. Crop Sci. 45:546–552.

Fox, T.R., N.B. Comerford, and W.W. McFee. 1990. Kinetics of phosphorus release from spodosol: Effects of oxalate and formate. Soil Sci. Soc. Am. J. 54:1441–1447.

Hay, F.J., D.M. Vietor, C.L. Munster, R.H. White, and T.L. Provin. 2007. Leaching loss of NO_3–N and dissolved P from manure and fertilizer during turfgrass establishment. Plant Soil 296:1–17.

Jordan, J.E., R.H. White, D.M. Vietor, T.C. Hale, J.C. Thomas, and M.C. Engelke. 2003. Effects of irrigation frequency on turf quality, shoot density, and root length density of five bentgrass cultivars. Crop Sci. 43:282–287.

Littell, R.C., G.A. Miliken, W.W. Stroup, R.D. Wolfinger, and O. Schabenberger. 2006. SAS© for mixed models. 2nd ed. SAS Inst., Cary, NC.

Morton, T.G., A.J. Gold, and W.M. Sullivan. 1988. Influence of overwatering and fertilization on nitrogen losses from home lawns. J. Environ. Qual. 17:124–130.

Noe, G.B., D.L. Childers, and R.D. Jones. 2001. Phosphorus biogeochemistry and the impacts of phosphorus enrichment: Why is the Everglades so unique? Ecosystems 4:603–624.

Petrovic, A.M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Environ. Qual. 19:1–14.

Petrovic, A.M. 2004. Impact of soil texture on nutrient fate. Acta Hortic. 661:93–98.

Porter, P.S., and C.A. Sanchez. 1994. Nitrogen in organic soils of the EAA. *In* A.B. Bottcher and F.T. Izuno (ed.) Everglades agricultural area. Water, Soil, Crop and Environ. Manage. Univ. Press of Florida.

Reike, P.E., and B.G. Ellis. 1974. Effects of nitrogen fertilization on nitrate movement under turfgrass. p. 120–130. *In* E.C. Roberts (ed.) Proc. 2nd Int. Turfgrass Res. Conf., Blacksburg, VA. 19–21 June 1973. ASA and CSSA, Madison, WI.

Satterthwaite, L.N., A.W. Hodges, J.J. Haydu, and J.L. Cisar. 2009. An agronomic and economic profile of Florida's sod industry in 2007. Univ. of Florida, IFAS, Florida Agric. Exp. Stn., Florida Coop. Ext. Serv., Gainesville, FL.

Shuman, L.M. 2001. Phosphate and nitrate movement through through simulated golf greens. Water Air Soil Pollut. 128:1–11.

Snyder, G.H., B.J. Augustin, and J.M. Davidson. 1984. Moisture sensor-controlled irrigation for reducing N leaching in Bermudagrass turf. Agron. J. 76:964–969.

Snyder, G.H., E.O. Burt, and J.M. Davidson. 1980. Nitrogen leaching in Bermudagrass turf: 2. Effect of nitrogen sources and rates. p. 313–324. *In* R.W. Sheard (ed.) Proc. 4th Int. Turfgrass Res. Conf., Guelph, ON, Canada. 19–23 July 1981. The Ontario Agric. College, Guelph, ON.

Soldat, D.J., and A.M. Petrovic. 2008. The fate and transport of phosphorus in turfgrass ecosystems. Crop Sci. 48:2051–2065.

Starr, J.L., and H.C. DeRoo. 1981. The fate of nitrogen fertilizer applied to turfgrass. Crop Sci. 21:531–536.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, and S. Polasky. 2002. Agriculture sustainability and intensive production practices. Nature (London) 418:671–677.

Vitousek, P.M., J.D. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, W.H. Schlesinger, and D.G. Tilman. 1997. Human alteration of the global nitrogen cycle: Sources and consequences. Ecol. Appl. 7:737–750.