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Nitrate leaching under different levels of irrigation for three turfgrasses in southern Puerto Rico[1,2]

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ABSTRACT

Inadequate nutrient and irrigation management of turfgrass may result in nitrate (NO_3) losses by leaching, and may contribute to elevated NO_3-N concentrations in groundwater. A field study was conducted to evaluate the effect of three irrigation levels on the NO_3-N concentration in soil solution and the mass of total NO_3-N lost by leaching for three grasses: Bermuda [*Cynodon dactylon* (L.) Pers.], Centipede [*Eremochloa ophiuroides* (Munro.) Hack], and Zoysia manila [*Zoysia matrella* (L.) Merr.]. The study was conducted at Juana Díaz, Puerto Rico, on a San Antón soil (fine-clayey, montmorillonitic, isohyperthermic Cumulic Haplustolls) from June 2001 until September 2002. Soil water NO_3-N concentrations below the root zone were obtained from water samples collected from suction lysimeters. The levels of irrigation applied were 75, 100 and 125% of the daily evapotranspiration (ET),

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calculated by using the pan evaporation method. Grass was fertilized with 165 kg N/ha/yr, split into four applications. The Bermuda grass exhibited the highest rate of horizontal growth (cover), reaching maximum cover in 45 days, whereas the others reached maximum cover in 120 days. Bermuda grass was the most efficient in reducing the loss of NO_3-N, with a mean annual soil water concentration below the root zone of 3.24 mg/L, whereas Zoysia and Centipede grasses were less efficient with mean annual soil water concentrations below the root zone of 17.4 and 17.8 mg/L, respectively. The soil solution concentration of NO_3-N did not change significantly for the Bermuda grass with increases in the level of irrigation. However, lower mean annual NO_3-N concentrations were observed for the Centipede and Zoysia grasses at the irrigation levels of 100% and 75% ET, with mean values of 14.0 and 11.1 mg/L, respectively. The Bermuda grass had an acceptable color index at the 100% ET, and resulted in decreased NO_3-N concentrations and mass losses. On the other hand, Zoysia and Centipede grasses presented a commercially acceptable color index and minimal NO_3-N leaching at the 75% ET irrigation level. The results from this study provide valuable information related to water and nutrient management for the turfgrass industry in southern Puerto Rico.

Key words: Bermuda, Centipede, Zoysia, nitrate leaching, percolation, water balance

RESUMEN

Percolación y lixiviación de nitrógeno durante el establecimiento y mantenimiento de gramas de césped en el sur de Puerto Rico

Un manejo inadecuado de gramas de césped puede incrementar las concentraciones de nitrato (NO_3-) en el agua del suelo y causar mayor lixiviación de nitrógeno (N) a aguas subterráneas. Se realizó un experimento de campo en Juana Díaz, Puerto Rico, de junio 2001 a septiembre 2002. Se evaluó el efecto de tres niveles de riego en la calidad de la grama, la extracción de N, concentración de NO_3-N en la solución del suelo y la pérdida de NO_3-N usando tres gramas de césped: Bermuda [*Cynodon dactylon* (L.) Pers.], Ciempiés [*Eremochloa ophiuroides* (Munro) Hack.] y Zoysia manila [*Zoysia matrella* (L.) Merr.]. El suelo pertenece a la serie San Antón (fino arcilloso, montmorilonítico, isohipertérmico Cumulic Haplustolls). Las concentraciones de nitrato por debajo de la zona radicular se obtuvieron de lisímetros. Los niveles de riego aplicado fueron 75, 100 y 125% de la evapotranspiración diaria, calculada por medio del método del tanque de evaporación. Las gramas se fertilizaron con un total de 165 kg N/ha, dividido en cuatro aplicaciones al año. La grama Bermuda obtuvo la máxima cobertura en 45 días, mientras que las demás gramas obtuvieron máxima cobertura en 120 días. La grama Bermuda fue la más eficiente en reducir la concentración de NO_3-N, con una concentración promedio anual de 3.24 mg/L, mientras que las gramas Zoysia y Ciempiés fueron menos eficientes, con valores de 17.4 y 17.8 mg/L, respectivamente. Las concentraciones de NO_3-N no cambiaron significativamente para la grama Bermuda al aumentar el nivel de riego. Sin embargo, se obtuvieron menores concentraciones promedios anuales en Ciempiés y Zoysia con los niveles de riego de 100% y de 75%, respectivamente. La grama Bermuda obtuvo un buen índice de color, y reducción en la pérdida de NO_3-N en el nivel de riego de 100%. En contraste, las gramas Zoysia y Ciempiés presentaron un color aceptable y menor lixiviación de NO_3-N con el nivel de riego de 75%.

Palabras clave: Bermuda, Ciempiés, Zoysia, lixiviación de nitrato, percolación, balance hídrico

INTRODUCTION

Nitrogen (N) is the most frequent limiting nutrient during turfgrass establishment. In adequate amounts, it promotes vigor, good visual quality and resistance to pests and diseases (Bowman et al., 2002). The quantity of available N in most soils is usually not sufficient to maximize plant growth; therefore, it is necessary to regularly apply fertilizer N to maintain fast growth, high rate of coverage, and good overall visual appearance.

Nitrogen is a dynamic nutrient that undergoes numerous transformations and in the NO_3- form is highly mobile in the turfgrass cropping system (Petrovic, 1990). Fertilizer-N is the main form entering the agricultural system and can be lost in gaseous form, leaching, and surface runoff. Of all these processes, leaching can result in the greatest impact on the environment since NO_3-N in groundwater higher than 10 mg/L can increase the risk to human health, especially to infants (Prasad and Power, 1995). This level can be exceeded when combinations of high quantities of N and water are used in agricultural areas overlying sensitive aquifer systems (Rieke and Ellis, 1974).

Studies have demonstrated that the loss of NO_3-N by leaching in turfgrass cultures is diminished when the grass has high N use efficiency (NUE), which depends on the affinity between the NO_3- and the turfgrass root system (Petrovic, 1990; Morton et al., 1988). Cisar et al. (1989) found that the efficiency of NO_3- absorption varies with the type of grass, thus indicating that the selection of grass can help to diminish the loss of NO_3- by leaching. Bowman et al. (1998) compared two genotypes of *Agrostis plaustris* (Huds) that noticeably differed in the density and length of their root systems; they reported that the genotype with the deeper root system reduced NO_3- leaching by 50%. Haibo et al. (1997) found that genetic and morphological differences between the grasses *Poa portensis* (L.), *Lolium perenne* (L.) and *Festuca arundinacea* (Schreb) influence N leaching.

Scientists have found a strong linkage between N leaching and the amounts of N applied and frequency of irrigation. For example, Morton et al. (1988) quantified NO_3-leaching losses by collecting samples with lysimeters at a depth of 70 cm, and estimating water percolation by using the water balance method. They found that when irrigation exceeded evapotranspiration (ET) of the grasses [*Poa annua* (L.) and *Cynodon dactylon* (L.) Pers], it produced deep percolation that caused N losses of between 22 and 56%. In a greenhouse study using two genotypes of *Agrostis plaustris* (Huds), the leaching of nitrate was affected by the elapsed time between the application of the fertilizer and the irrigation (Bowman et al., 1998). Bowman et al. (2002) utilized mini-tanks as lysimeters to measure the amount of NO_3- leached and NUE under greenhouse conditions. They found that the average solution concentration (mg/L) for the grasses Centipede, Zoysia Meyer, Zoysia Emerald, Bermuda and St. Augustine was 7.5, 17.6, 7.3, 7.6 and 0.9, respectively. The proportion of N extracted was 71, 63, 77, 70, and 71% of that applied for Centipede, Zoysia Meyer, Zoysia Emerald, Bermuda, and St. Augustine grasses, respectively, with the amount extracted probably related to root architecture.

In areas where precipitation is limiting, irrigation is an integral part of any grass management program. Root distribution influences the amount of soil moisture necessary to maintain the growth of the grasses. Qian and Fry (1996) reported that *Zoysia japonica* Steud (*Zoysia Meyer*) exhibited a good visual quality and excellent root development when a daily volume of irrigation equivalent to 100% of the daily ET was applied, all of which was measured directly with the use of mini-lysimeter and using the water balance method. In this experiment, the ET measured directly was best related to the Black-Bellani method (R^2= 0.73), followed by the pan evaporation method (R^2= 0.67) and the Penman-Monteith method (R^2= 0.60). Peacock and Dudeck (1984) reported good quality for the St. Augustine grass (*Stenotaphrum secundatum*) when irrigated at intervals of two, three, four and six days, with a volume of application based on the daily ET when using the Penman-Monteith method.

Nitrogen leaching can be reduced with a reduction in applied water (Tovey et al., 1969). La Rue et al. (1968) found that reducing the frequency of application reduced the quantity of water lost to deep percolation. Brown et al. (1977) studied Bermuda grass (*Cynodon dactylon* L.) under three levels of irrigation: 0.6 to 0.8, 0.8 to 1.0 and 1 to 1.2 cm/application, applied three times a week, combined with varying N levels. They found that the quantity of the NO_3-N lost by leaching varied according to the levels of nitrogen and water applied. When the irrigation level approached the ET rate, the loss of nitrate was reduced.

The commercial production of turfgrass in the tropics has become a profitable activity, where cultures like Bermuda, Zoysia and Centipede have been used intensely in recreational areas, residential areas, sport fields and public areas (Philip, 1989). According to the Golf Association of Puerto Rico, there are eighteen golf courses in Puerto Rico occupying a total area of 1,165 ha (Vélez, 1998). There is approximately 329 ha of land that is being used in the commercial production of grass, whose value was considered to be $7 M for the year 2001, an amount which represented 1% of the agricultural gross revenue for the same year (DA, 2001).

Given the increasing importance of the turfgrass industry in Puerto Rico and lack of a technical guide for turf management for the Caribbean Region, it is necessary to evaluate how turfgrass responds to irrigation management during establishment and maintenance. The objectives of this study were to determine the effect of levels of irrigation on the growth, quality, N extraction, dry matter production, NO_3-leaching and mass losses of three turfgrass species that are of commercial importance in Puerto Rico.

MATERIALS AND METHODS

Experimental overview

The field experiment was conducted from May 2001 to September 2002 at the Agricultural Experiment Station in Juana Díaz, Puerto Rico. The station is located within the semi-arid southern coast at 18°01'N (latitude), and 66°30'W (longitude), 21 m above mean sea level. The soil at the site corresponds to the San Antón series (fine-clayey montmorillonitic, isohyperthermic Cumulic Haplustolls) with a pH of 7.4.

Treatments were a factorial combination of three irrigation levels (75, 100 and 125% of reference ET) and three turf grasses. Grasses were: Zoysia manila, Bermuda, and Centipede grass. Irrigation treatments were based on reference evapotranspiration measured at the site using the pan evaporation method of González and Goyal (1989).

$$ET_o = K_p E_{pan} \quad [1]$$

$$IR = (ET_o K_c) - R_e \quad [2]$$

where E_{pan} is the pan evaporation; K_p is the pan evaporation coefficient; ET_o is the reference ET; IR is the depth of water applied; K_c is the crop coefficient, and R_e is the effective rainfall depth. The evaporimeter consisted of a circular tank of 133.3-cm diameter and 25-cm depth. A K_p value of 0.85 was established based on suggested values from different areas of the island (Goyal, 1989). Jensen et al. (1990) reported that the K_c values for turf grasses range from 0.60 to 0.75; however, Carrow (1995) determined K_c values of 0.68, 0.81, and 0.85 for Bermuda, Zoysia, and Centipede grass, respectively. Because specific K_c values were not available for the island, a value of 0.75 was used throughout the study period.

Plant materials were established 24 May 2001 by using cylindrical plant plugs. The experimental design was a randomized complete block in a split-plot arrangement with three replications. The irrigation regime was the main plot, and the sub-plot corresponded to grass species.

The plugs were established at a density of 10 x 10 cm with four rows of four cylinders each for a total of 16 cylinders per plot. The experimental plot area was established based on the sprinkler irrigation wetted area of 23.65 m^2.

The fertilization program consisted of 165 kg N/ha/yr split-applied in four applications, 15 days after plant establishment and at three-month intervals thereafter. The N sources were ammonium sulfate and urea at a 1:1 ratio. Phosphorus and potassium were applied at rates of 55 kg P_2O_5/ha as triple superphosphate and 200 kg K_2O/ha as muriate of potash in two applications.

Plant cover and lateral growth of turf grasses

Lateral growth was evaluated by using a cross-sectional grid overlaid on clear plexiglass. Two of the four center plant plugs were randomly selected. The distance from the center of each plug in which plant vegetative material appeared was recorded at eight equilateral points. A mean radius value (r) was recorded and the plant cover was calculated by using the formula

$$S = \pi r^2 \qquad [3]$$

where S is the plant cover area, and r is the mean value of the distance radiating from the center. Growth data was collected at bi-weekly intervals until plant cover was complete. Values were expressed relative to maximum area coverage.

Dry matter production and nitrogen content

Plant dry matter was determined every 15 days from vegetative material harvested within the center of each plot at a height of 5 cm (Biran et al., 1981). Material was dried at 70° C for 48 h and the dry weight determined. The N content in plant dry matter was determined by using the method of Horwitz (2000). Nitrogen content was calculated by multiplying dry matter production by N concentration, and it was expressed on a mass per unit area basis (kg/ha).

Grass quality

Grass quality is described primarily on the basis of color, texture, and growth patterns (Hanson and Juska, 1969). In this experiment grass quality was measured every 15 days prior to mowing, and was based solely on grass color with a visual numeric scale of 1 to 5, where 1 was dead grass, 3 was commercially acceptable grass and 5 was a green intense color (Goatley et al., 1998).

Nitrate concentration in soil water

A suction porous-cup lysimeter (1.5-cm diameter × 2.5-cm length) (Soil moisture Equipment Corp; Santa Bárbara, CA) attached to a 1.5 cm polyvinyl (PVC) pipe was installed near the center of each plot to draw soil solution samples from a depth of 0.9 m. The lysimeters were installed from 24 to 26 May 2001. Samples were first collected for analysis 18 June 2001 and then collected at bi-weekly intervals thereafter until 16 June 2002. Suction was applied at -60 kPa on the day prior to sample collection by using a suction hand pump. Samples were aspirated into modified side-arm Erlenmeyer flasks that were rinsed with 0.1 N HCl and distilled water prior to collection. They were then transferred to 25-mL polyethylene scintillation vials, placed in a cooler (4° C) and promptly transported. Ammonium and nitrate concentrations were determined by using a Bran+Luebbe Autoanalyzer (Technicon Industrial Systems), following USEPA methods 350.1 (USEPA, 1993) and 353.1 (USEPA, 1983), respectively.

Nitrogen mass loss estimates

A daily water balance was performed to quantify the water depth that percolated beneath the soil profile, to evaluate the irrigation level utilized, and to identify NO_3-N leaching events. The model consisted of adjusting the initial soil moisture content to predict soil moisture on days after each sampling event with the following equation:

$$SM_{i+1} = IR_{i+1} + R_{i+1} - ETc_{i+1} - R_{Oi+1} + SM_i \quad [4]$$

where SM_{i+1} was the soil moisture content (mm) within the root zone on day i+1; IR_{i+1} was the total water applied by irrigation on day i+1; R_{i+1} was the rainfall depth on day i+1; ETc_{i+1} was the ET accumulated during day i+1; Ro_{i+1} was the estimated water losses due to runoff on day i+1; SM_i was the soil moisture content on day i. It was assumed that percolation occurred when the water depth that entered the soil exceeded the soil water holding capacity (or field capacity) of 198.2 mm (mean value of 32.5% volumetric water content) within a 0.61-m depth. Gravimetric soil moisture content of the profile was performed 1 June 2001, 1 November 2001, 11 February 2002, 11 June 2002, and 5 September 2002. Samples were collected at depths of 0 to 20, 20 to 40, 40 to 60, and 60 to 80 cm within each plot. The percolated water depth (P_{i+1}) was estimated by using the equation:

$$P_{i+1} = SM_{i+1} - FC \quad [5]$$

where FC is the soil water content at field capacity moisture and SM_{i+1} was defined previously. If P_{i+1} was greater than zero, then S_{i+1} was set equal to FC. If P_{i+1} was less than zero, then P_{i+1} was set equal to zero. Rainfall (R_{i+1}) and other climatic variables were registered electronically at a weather station situated 0.5 km from the study area. Crop evapotranspiration for all plots was calculated by using the equation:

$$ET_c = K_c\, ET_o \qquad [6]$$

where Kc is the crop coefficient; ET_o (mm/day) is the reference ET using the Penman-Monteith model (Allen et al., 1998).

Runoff (RO) was calculated by using the curve-number method of the then Soil Conservation Service (SCS, 1972):

$$RO = (R-0.2S)^2/(R+0.8S) \qquad [7]$$

$$S = (25400/CN) - 254) \qquad [8]$$

where R is the precipitation, S is the maximum potential difference between rainfall and runoff at the moment of rainfall initiation; CN is the curve number which is a proportion of rainfall converted to runoff. The CN value was adjusted on the basis of the depth of water added to plots (rainfall plus irrigation) that was applied during the prior five days with the following conditions (Schwab et al., 1981):

$$CN = 40.87 \text{ (when water depth was < 36 mm)} \qquad [9]$$

$$CN = 61 \text{ (when water depth was 36 to 53 mm)} \qquad [10]$$

$$CN = 79.3 \text{ (when water depth was > 53 mm)} \qquad [11]$$

The total NO_3-N mass leached for each turfgrass was calculated based on the product of NO_3-N concentrations in soil water from lysimeters sampled at bi-weekly intervals and percolated water.

$$P_{tn} = (P_{it}\, C)/100 \qquad [12]$$

where P_{tn} is the total nitrate mass loss (kg/ha); P_{it} is the water depth percolated; C the nitrate concentration in solution; and 1/100 is the conversion factor. When potential leaching occurred, NO_3-N concentrations used were the mean values from the nearest sampling events.

Statistical Analysis

Data were analyzed to assure normal distribution and variance homogeneity using the Statistical Analysis Software (SAS Institute, Inc.

2000). Differences among means were separated by using Tukey multiple range test at a significance level of 5%.

RESULTS AND DISCUSSION

Grass cover and lateral growth during establishment

Maximum growth cover was reached within the first 120 days (Figure 1). It was first reached by Bermuda at 45 days, second by Centipede at 105 days and last by Zoysia at 120 days. There was no significant difference in the rate of growth between Centipede and Zoysia. Bermuda grass had the highest rate of coverage (79.4%) during the period between 30 to 45 days after planting. Highest rates of coverage for Centipede and Zoysia (43.4 and 32.3%) occurred 75 to 90 and 90 to 105 days after planting, respectively.

The slower growth of Zoysia and Centipede, in comparison with that of Bermuda grass, could make their establishment difficult in some environments. Some studies suggest that N fertilization during the establishment of Zoysia has a minimal effect on plant growth (Carroll et al., 1996). Fry and Dernoeden (1987) reported that during the first year there was no response of Zoysia to the application of nitrogen but there

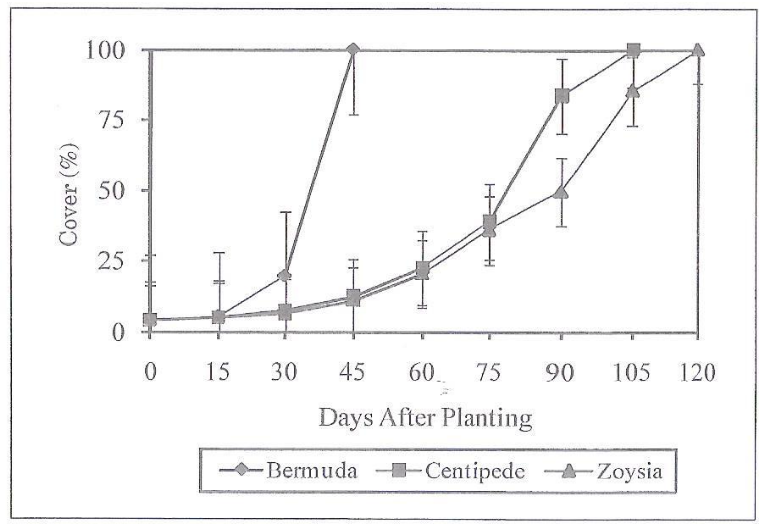

FIGURE 1. Cumulative percentage of cover for the three turf grasses (Bermuda, Centipede and Zoysia). Error bars with standard error are shown.

was a very significant response during the second year of maintenance. The slow establishment of the Zoysia and Centipede could be related to a poorly developed root system; thus greater amounts of N could be lost during this period. The slower growth rates of these two grasses should be taken into consideration when planning fertilizer management programs.

Production of dry matter and nitrogen content

There were no significant differences among the levels of irrigation with respect to dry matter production during establishment and maintenance. However, the amount of dry matter produced varied among the grasses at different times of the year (Table 1). On some dates, Zoysia and Centipede had more dry matter than Bermuda. Overall, Bermuda grass produced greater amounts of dry matter (10,357 kg/ha/yr) than Zoysia (8,646 kg/ha/yr) and Centipede (6,254 kg/ha/yr).

Bermuda grass extracted the greatest amount of N (191.7 kg N/ha/yr), followed by Zoysia (137.4 kg N/ha/yr), and then by Centipede (113.4 kg N/ha/yr). The nitrogen use efficiency (NUE) is defined as the production of dry matter per unit of nitrogen (N content) present in the tissue. The respective NUE values for the Bermuda, Zoysia and Centipede were 54.0, 62.9 and 55.1; Zoysia was most efficient at utilizing nitrogen.

TABLE 1.—*Temporal variation and cumulative dry matter production in three turfgrasses in Juana Díaz, Puerto Rico. Values are averaged across irrigation levels.*

Date	days after planting	Turfgrass		
		Bermuda	Centipede (kg/ha)	Zoysia
7/20/01	57	1223.3	*	*
08/8/01	76	1056.0	*	*
8/29/01	97	948.3	*	*
9/26/01	125	790.2 a[1]	580.8 a	774.0 a
10/15/01	145	85.2 b	470.0 a	443.1 a
11/15/01	175	281.6 b	744.2 a	639.1 a
12/6/01	196	391.6 a	669.3 a	398.0 a
12/29/01	219	1120.9 a	853.8 a	1298.2 a
2/7/02	259	680.7 a	527.2 a	938.2 a
3/13/02	293	810.0 b	938.2 a	779.5 c
4/19/02	330	799.2 a	322.2 b	796.9 a
6/16/02	385	2170.6 a	1149.2 b	2279.1 a
	Cumulative (kg/ha/yr)	10357.5	6254.9	8646.1

[1]Values with different letters within the same row are significantly different according to the Tukey's test at $P < 0.05$.

*The grasses did not reach the height established from the 5 cm cut.

Grass Quality

All three grasses had similar quality during the first 145 days of the experimental period (Table 2). This finding was likely due to higher levels of available soil N and lower root volumes during this period. After this period, differences among grasses appeared for the varying irrigation levels. Bermuda exhibited a reduction in quality (on day 196) with a color index not commercially acceptable (≤3.0). Conversely, Zoysia and Centipede never reached that minimum color value. On average, color index values were 4.2, 4.5 and 4.6 for Bermuda, Centipede and Zoysia grass, respectively.

Soil Solution NO_3-N

Significant differences were found in soil water NO_3-N concentrations among the grasses during the 21 samplings made from June 2001 to June 2002. Although there were no significant differences among levels of irrigation there was a significant interaction between the grasses and the levels of irrigation (Figure 2). Soil water NO_3-N concentration was not affected by levels of irrigation in Bermuda grass, possibly because of its large root mass which allows it to extract NO_3-N even when more water is applied. Nevertheless, the lowest concentration of NO_3-N for Centipede occurred at the 100% ET irrigation level, which was statistically different relative to the 75% and 125% ET irrigation levels. For Zoysia, the lowest soil water NO_3-N concentration was observed at the 75% irrigation level and increased with the level of applied irrigation. On the basis of this finding, it is likely that more root mass developed at the 100% and 75% ET irrigation levels in Centipede

TABLE 2.—*Mean visual color index for three turfgrass species and irrigation levels average color scale for all the different species in the three different levels of irrigation.*

Irrigation Level (% ET)	Grass	Days after Planting										
		57	76	97	125	145	175	196	219	259	293	330
75	Bermuda	5.0	5.0	5.0	5.0	5.0	4.0	2.8	3.3	3.3	3.3	3.0
75	Centipede	5.0	5.0	5.0	5.0	5.0	4.5	3.8	4.0	3.8	3.5	3.0
75	Zoysia	5.0	5.0	5.0	5.0	5.0	4.3	3.8	4.3	4.0	4.0	4.0
100	Bermuda	5.0	5.0	5.0	5.0	5.0	4.0	3.5	4.0	4.0	3.5	3.0
100	Centipede	5.0	5.0	5.0	5.0	5.0	4.3	4.0	4.3	4.3	3.5	3.0
100	Zoysia	5.0	5.0	5.0	5.0	5.0	4.5	4.0	4.5	4.8	4.0	4.0
125	Bermuda	5.0	5.0	5.0	5.0	5.0	4.5	3.5	3.5	4.3	3.3	3.0
125	Centipede	5.0	5.0	5.0	5.0	5.0	5.0	4.5	4.0	4.3	4.0	3.3
125	Zoysia	5.0	5.0	5.0	5.0	5.0	4.8	4.8	4.5	5.0	4.3	4.0

*Rank of visual color base on a scale of 1 = completely dead, 3 = acceptable minimum color, 5 = intense green color.

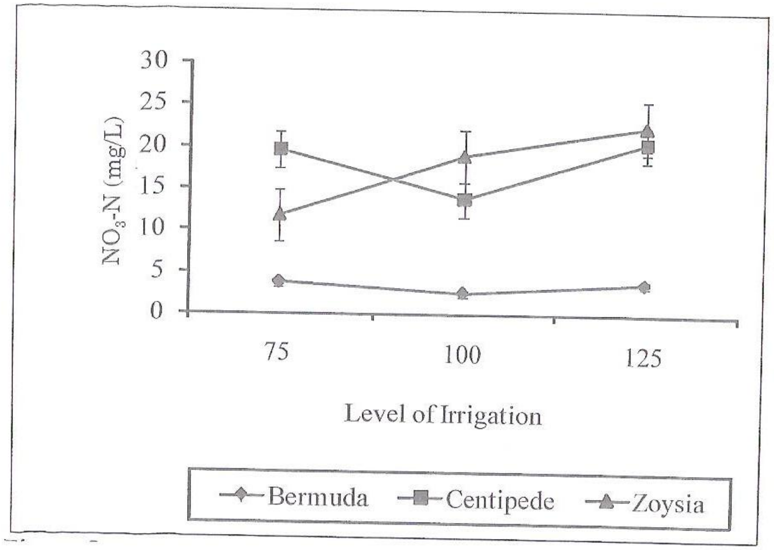

FIGURE 2. Average concentration of NO_3-N in the soil solution for three turf grasses and the irrigation level. Error bars with standard error are shown.

and Zoysia, respectively, presumably translating into greater utilization and decreased soil solution of NO_3-N. Soil water NH_4-N values below detection limits suggest that anaerobiosis was not achieved in the soil profile even at the highest irrigation levels. Of the grasses evaluated, Zoysia is considered the most resistant to drought (White et al., 2001). As soil moisture decreases, Zoysia has the capacity to reduce the rate of transpiration (Biran et al., 1981). It is possible that this smaller demand of water by Zoysia allowed it to adapt itself satisfactorily to the lower level of irrigation (75%).

The NO_3-N concentration during the first five samplings was relatively high when compared to the 10 mg/L maximum concentration level for drinking water established by the U.S. Environmental Protection Agency (PREQB, 2003), especially for Centipede, which had a maximum value of 52.9 mg/L (Figure 3). This value may have occurred because of N mineralization from organic N present in the soil profile, combined with low crop N demand due to a less developed root system. After the Bermuda grass covered the soil surface (day 45), the concentration of NO_3-N never exceeded 10 mg/L. Nevertheless, it was not until

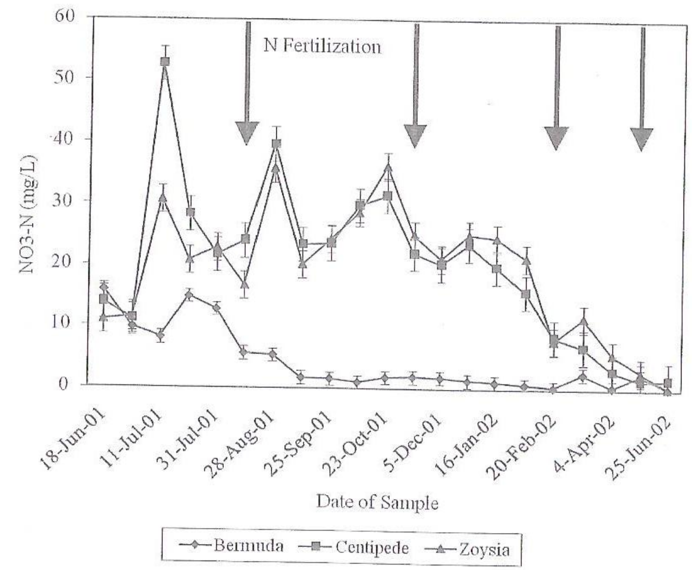

FIGURE 3. Temporary variations in the average concentration of nitrate nitrogen (NO_3-N), for each grass during the period from June 2001 to June 2002. Error bars with standard error are shown.

February 2002 that a significant reduction of NO_3-N was apparent, <10 mg/L, for Centipede and Zoysia. This tendency was maintained until the end of the experiment.

The soil solution samplings obtained between February and June 2002 appear to be representative of a stable root system. Several factors could explain the reduction in the leaching for those months: 1) The grasses could have developed a larger root system, all of which makes them more efficient in the use of nitrogen; 2) This period of minimum nitrate leaching coincided with a reduction in rainfall and in some cases with the reduction in dry matter produced (Table 1). This result suggests that there was a reduction of plant-available NO_3-N due to plant demands and less water available in the soil profile and less potentially leachable nitrate. Further, carbon from root exudates and metabolites from the grass to soil could have stimulated microbial activity and therefore increased N immobilization (Bowman et al., 1989).

Fertilization timing is an important factor in the loss of nitrate. Centipede and Zoysia turfgrass environments had the highest soil solution NO_3-N concentrations, both exceeding the 10 mg/L critical value in most sampling events (Figure 3). In contrast, soil solution NO_3-N concentrations in Bermuda grass did not vary much, thus indicating a high N demand. Averaged across sampling dates, the concentration of NO_3-N in Bermuda grass was below the critical 10 mg/L level at 3.2 mg/L, whereas Centipede and Zoysia had similar average concentrations of 17.8 and 17.4 mg/L, respectively. Our results are similar to those of Bowman et al. (2002) where Bermuda and St. Augustine grasses were most efficient in reducing nitrogen leaching, because of the high rate of N removal by the dense deep root systems.

NO_3-N mass losses

During the 15 months in which the soil lysimeters were monitored, there were 101 rainfall events and 140 irrigations that generated drainage below the root zone. The total (rain plus irrigation) was 1939, 2284 and 2634 mm for irrigation treatments 75, 100 and 125% ET, respectively. Percolation losses for these treatments determined by the water balance method were, respectively, 226 mm, 455 mm and 621 mm. There were no differences found among the grasses with respect to the volume of total drainage water throughout the year. However, in soil samplings made on 11 June 2002, Bermuda grass had lower soil moisture contents than the other grasses at the 125% ET irrigation level, all of which may have been due to a greater consumption of water by this grass (Figure 4).

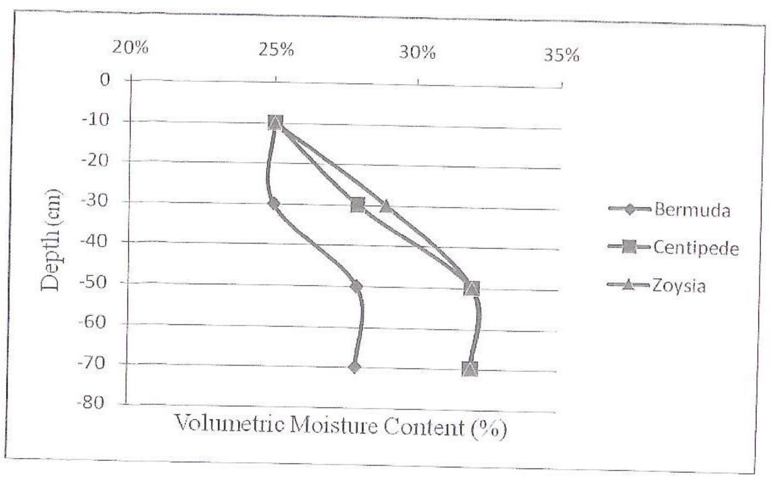

FIGURE 4. Soil moisture content in relation to the depth and grass type, corresponding to the level of 125% ET on 11 June 2002.

The total amount of drainage water varied directly with the quantity of water applied (rainfall plus irrigation) in the area of the study. August 2001 was the month in which the greatest volume of water was applied and in which runoff occurred. In the period between September 2001 and February 2002, a distinct reduction in drainage was observed, coincidental with a reduction in quantity of water applied (Figure 5).

Cumulative amounts of NO_3-N leached for the three grasses are presented in Table 3. The greatest proportions of NO_3-N leached occurred during the months of August and September 2001; these amounts are equivalent to 100, 96, and 24% of the N applied for Centipede, Zoysia, and Bermuda, respectively. This leaching occurred because the greatest rainfall events occurred during these months and within days after fertilization.

Irrigation treatment with 75% ET significantly reduced leaching of NO_3-N in all grass plots. With this treatment, the soil moisture content, especially for Zoysia and Centipede, was always near field capacity, and

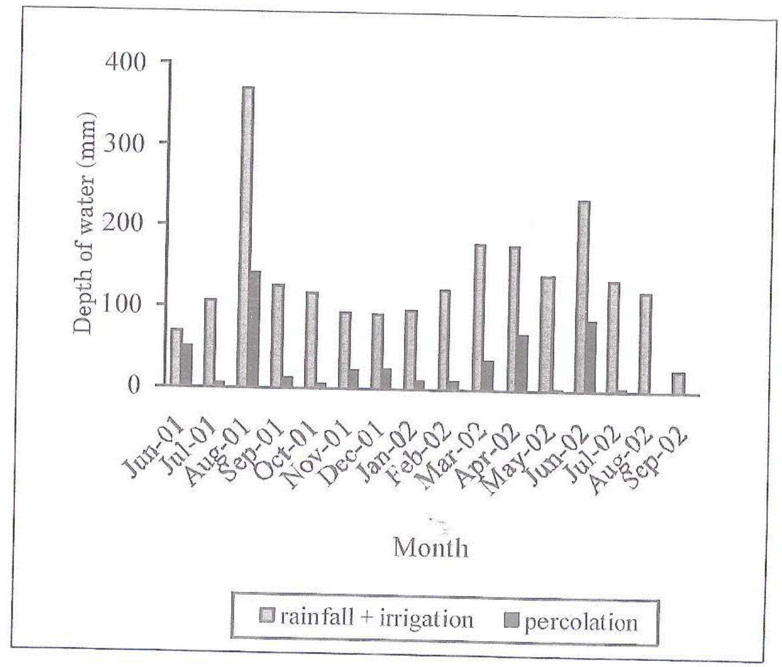

FIGURE 5. Monthly precipitation and irrigation and the average percolation from all the treatments.

TABLE 3.—*Cumulative amounts of NO_3-N leached (kg/ha/yr) for the Bermuda, Centipede and Zoysia grasses, and corresponding percentages of the N applied, for irrigation levels of 75, 100 and 125% evapotranspiration (ET).*

ET Irrigation Level	Bermuda	Centipede	Zoysia
75%			
Leached NO_3-N	17.5	57.3	43.8
% of N applied	11.0	34.7	26.6
100%			
Leached NO_3-N	11.5	63.7	78.8
% of N applied	7.0	38.6	47.7
125%			
Leached NO_3-N	38.8	127.7	125.1
% of N applied	23.5	77.4	75.8

values of soil moisture for the Bermuda grass were slightly drier. Because irrigation was performed solely upon the basis of estimated water balance, independently of the soil moisture level, this amount resulted in excess water being applied for some treatment-grass combinations. Soil moisture monitoring is thus important in order to corroborate water balance models, and to improve water management in these systems.

CONCLUSIONS

Bermuda grass was the most efficient turfgrass in reducing NO_3-N leaching, apparently because of greater N demand due to a denser and deeper root system and higher dry matter production. These characteristics make Bermuda grass a good candidate for minimizing potential groundwater contamination by nitrate. Irrigation level 75% ET is recommended for the establishment and maintenance of Zoysia and Centipede grasses. At this irrigation level, minimum leaching occurred, and the color index values remained above the minimum commercially acceptable value of 3.0. Because Bermuda grass has a high capacity to extract N and apparently a larger demand for water, it is recommended that it be irrigated with 100% of the ET. At this irrigation level, minimal leaching occurred, and the color index value remained at or above the commercially acceptable value.

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