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ROOT AND SHOOT PERFORMANCE OF THREE CREEPING BENTGRASS CULTIVARS AS AFFECTED BY NITROGEN FERTILITY*

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ABSTRACT

Cultivar selection and nitrogen (N) fertility significantly influence the performance of creeping bentgrass *(Agrostis palustris* Huds.) in warmer regions of the United States. This study was conducted to determine the effects of N on root and shoot growth of three creeping bentgrass cultivars. The effect of three N rates (195.3, 390.6, and 586.0kgN/ha year) on the total root length density (TRLD), deep root length density (DRLD), visual shoot quality, shoot density, and root to shoot ratio (RSR) of 'Crenshaw', 'L93', and 'Penncross' creeping bentgrass were evaluated in the University of Georgia Rhizotron at Athens, GA. Over the 19 month study, cultivar type and N rate significantly affected root and shoot growth with slight interaction. Crenshaw and L93 showed greater TRLD, DRLD, and visual shoot quality than Penncross at the 390.6 kg N rate. RSR was significantly

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influenced by N rate but not cultivar type. Both L93 and Crenshaw possessed significantly higher RSR at the 195.3 kgN rate than the 586.0kgN rate.

INTRODUCTION

Creeping bentgrass *(Agrostis palustris* Huds.) is a perennial cool-season grass, native to Eurasia but adapted for use in many areas throughout the world. It is named creeping bentgrass because of its vigorous creeping stolons that develop at the surface of the ground and initiate new roots and shoots from the nodes (1). It is an aggressive, fine-textured, sod-forming grass that can tolerate very low mowing heights and provides a dense, uniform, high quality turf. For these reasons creeping bentgrass has been the overwhelming choice for lawn bowling greens, golf course greens, tees, fairways and croquet fields, throughout much of the United States. Creeping bentgrass does persist during midsummer heat stress, but shoot and root growth are seriously impaired resulting in significant reduction in turfgrass quality (2). Improvements in summer shoot density (3) and root growth (4, 5) have been reported using new cultivars of bentgrass.

Nitrogen fertilization is an important cultural technique in the management of creeping bentgrass. Nitrogen fertility rate has shown direct relation to creeping bentgrass shoot density, growth and color (6, 7, 8, 9). Increases in creeping bentgrass shoot growth are observed as N fertility levels exceed zero. However, effect of N rate on shoot growth and recuperative potential has been shown to interact with temperature. Hawes and Decker (10) evaluated recuperative potential of creeping bentgrass at various N rates and temperatures. At 21°C, the highest N rate resulted in the highest rate of recuperation. On the contrary, recuperation rate of the high N rate at 32°C was significantly lower than the rate observed at low and medium N rates.

The effect of N rate on root growth and root length density has not shown as distinct an association. Christians et al. (11), found an inverse-quadratic response of creeping bentgrass root weight to N fertility in a growth chamber experiment. Further chamber creeping bentgrass experimentation by Schmidt and Blaser (9) showed significant negative correlation of root weight to N fertilization rate. Madison (12) determined root length density of 'Highland' colonial bentgrass *(Agrostis tenuis* Sibth.) to be significantly reduced by increasing N fertilization rates in a field study.

Conversely, other studies report positive correlations between N and bentgrass root growth. A greenhouse study showed bentgrass fertilized at 600 kg N/ha~ season had greater root weight than when fertilized at 1.5 kgN/ha season

(13). Bell and DeFrance (14) determined root density of 'Washington' creeping bentgrass to be positively correlated to N content in the fertilizer of treated field plots. These inconsistencies, common to bentgrass root research, may in part result from the relationship of root length density (RLD) to shoot density at shallow soil depths. Improvements have been made by reporting bentgrass root-to-shoot ratios (RSR), specific root lengths (SRL) (15), and viable root length measurements (16, 17, 18).

The objective of our experimentation was to evaluate under field conditions, root and shoot growth of creeping bentgrass cultivars under different N fertilization levels.

MATERIALS AND METHODS

This study was conducted in the University of Georgia rhizotron at Athens, GA. A rhizotron is an underground root observation laboratory with several individual soil-filled observation chambers with transparent viewing walls (19). The facility allows vegetative plant growth to occur outdoors under field conditions while the root systems of those plants may be continually monitored *in situ.* The major advantage of studying plant roots in a rhizotron is root morphology and function can be observed extensively while the root system remains intact (20). The University of Georgia rhizotron has 12 observation chambers 1 by 1 and 1.85 meters deep that line each side of its 13.7m central underground walkway. The observation window of each chamber consists of a single pane of 2.0 cm thick tempered plate glass set at 12.5 degrees from vertical with the other three walls of each chamber being composed of cinder block. Nine of the 24 chambers were prepared and used in this study.

A wire screen was placed over a 15 cm ID drainage hole at the bottom of each chamber and covered with 5 cm of coarse gravel. The chambers and contents were then rinsed with a 1.1% sodium hypochlorite solution and allowed to drain. A coarse sand was then packed into each chamber to a height of 139 cm in 15 cm increments. The bulk density of each installed increment was measured with a Troxler Model 3411B Moisture Density Gauge (Troxler Laboratories, Research Triangle Park, NC) and maintained between 1.3 and 1.4gcm~^{3}. Layering between increments was prevented by lightly scratching the top 2 cm of each increment with a rake prior to the next addition of sand. The nine observation chambers were divided with 1 cm thick plexiglass into 36 chambers 1 m long and 25 cm wide. A 10.2 cm gravel blanket was poured into each compartment and leveled. A 5.1 cm intermediate layer of coarse mortar sand was packed onto the gravel layer. The upper 30.5 cm of each chamber was filled with an 85/15 sand/peat root mix (v/v %) and packed into each chamber in 10 cm increments. All materials used in chamber preparation met the physical specifications of USGA greens construction method (21). Layering was prevented by the method mentioned previously and bulk density maintained between 1.45 and 1.55 $g em^{-3}$.

On 23 February 1997, sod of L93, Crenshaw, and Penncross cultivars of creeping bentgrass was cut from the Rapid Turf, Inc. Sod Farm (Rincon, GA) and transported to Athens, GA. On 1 March, 1997 the sod was power-washed to remove all soil, cut into 25 cm by 100 cm strips, and roots clipped back to the mat/crown region before installation onto the chambers. On 2 March, 1997, the areas between and immediately adjacent to the chambers and the roof of the rhizotron were leveled and sodded with Penncross sod. The sod border was 31 cm wide. From 4 March through 20 March 1997 the plots were mowed every other day at 0.6 cm and topdressed with the root zone mix every four days. From 21 March through 2 April 1997 the plots were mowed daily at 0.5 cm and lightly top dressed on March 25 and 30. On 10 April 1997, mowing height was lowered to 0.4 cm and the plots mowed daily through the remainder of the experiment.

The turfgrass plots were mowed daily at 0.4 cm and irrigated as a whole as necessary to prevent wilt. Chlorothalonil, mancozeb, and iprodione fungicides were applied on a curative basis when necessary. Fosetyl-aluminum and metataxyl fungicides were applied on a preventive basis when weather conditions favored *Pythium* development. Trichlorfon was applied at label rates for white grub and cutworm control when necessary. Weed encroachment was monitored weekly and weeds removed by hand. The turfgrass plots were top dressed with 8 m^3 ha^{-1} of the root zone mix on 22 July, 4 September, 22 September, 12 November 1997, 24 January, 14 March, 18 May, and 14 June 1998.

Beginning 6 March 1997 all plots were fertilized with water soluble fertilizer (Peter's 10-10-10) at the rate of 12.2kgN/ha of nitrogen, phosphorous and potassium every seven days through 10 April. The three fertility treatments of 7.5, 15, and 22.5kgN/ha applied every 14 days using a modified Hoagland's solution were initiated on 18 April 1997 and provided annual rates of 195.3, 390.6, and 586kgN/ha. The 195.3 kgN/ha was applied to all plots and borders with a three nozzle $C0_2$ sprayer at a rate of 315 L/ha. The additional 195.3 and 390.6kgN/ha for both the medium and high treatments were applied by drenching each plot with 250 mL of 0.027 and 0.054 M ammonium nitrate solution, respectively. The N in all fertilizer solutions was applied in equal proportions of NH4 and NO3, as described by McCrimmon and Karnok (22). The low treatment plots received a 250 mL drenching of de-ionized water.

Shoot color and quality measurements were made monthly for each plot. Quality ratings were based on 9 being the highest and 1 being lowest. Turf quality evaluations were determined by assessing color, uniformity, density, texture, growth habit, and smoothness of the turf (1). Shoot density measurements were taken at the end of each season by removing three soil cores with a 1.9 cm ID soil probe from three random locations of each plot. Verdure was separated from the cores and the number of shoots counted. Shoot density was divided by total root length density to determine root to shoot ratios (RSR).

Root observations were taken approximately every 14 days on a 8 x 32 cm grid located in the center of the viewing window. Long wave ultra-violet (320-400 nm) light (Model B-100A/R Blak-Ray Ultra-Violet Lamp, UVP, Inc., San Gabriel, CA) was used to facilitate viewing of actively growing viable roots (16, 17, 23). Root measurements commenced 12 April 1997 and terminated 25 September 1998, totaling 39 independent observations. Seasonal analysis was determined by calender months; spring consisted of all observations taken in April, May, and June; summer, July, August, and September; fall, October, November, and December; and winter, January, February, and March. Seasonal data were composed of either six or seven observations.

Root length was determined using the line intersect method as described by Newman (24) and later modified by Tennant (25). The modified formula is represented as: RL = N x CF where: RL = root length, N = number of intercepts and CF = conversion factor. The conversion factor was determined by multiplying 11/14 by the grid unit. In this study 2 cm grid squares were used, therefore, the length conversion factor was 1.5714. Root length density (RLD) measurements are preferred to root lengths per unit area, as root water and nutrient uptake are best related to RLD and models of uptake use RLD data (26). Therefore, we multiplied visible root length per unit area by the estimated depth of view into the soil for traceable roots (27, 28, 29, 30, 31). Commonly used soil depths are 1 to 3 mm, we used a value of 2 mm (28, 30). Due to structural supports inherent to the rhizotron construction, the top 2 cm of the soil profile were not visible. Therefore, total root length (TRLD) measurements consisted of all viable root length at depths greater than 2 cm, while deep root length (DRLD) is viable root length at depths greater than 19 cm.

Experimental design was a complete randomized block with four replications of three factorial nitrogen treatments and three cultivars. Seasonal data consisting of 6 or 7 observations were treated as repeated measures or split-plots in time and were analyzed using the PROC ANOVA subroutine of SAS (32). Bartlett's test for homogeneity of variance (a = 0.05) was performed and data sets failing to meet the equal variance assumption (TRLD and DRLD) were successfully transformed by natural log and re-analyzed (33).

RESULTS AND DISCUSSION

Root Growth

Mean total root length density (TRLD) was significantly affected by cultivar, N rate, and season without interaction (Tables 1 and 2). Season had a significant

Table 1. ANOVA Table for Dependent Variables by Cultivar, Nitrogen Fertility Rate, Season, and Interactions

Source	df	Total Root Length Density (TRLD)	Deep Root Length Density (DRLD)	Shoot Quality	Shoot Density	Root:Shoot Ratio
		F-value				
Cultivar	2	2.78*	4.56**	27.04***	19.16***	0.01
N rate	2	3.60**	1.22	209.12***	51.31***	12.39***
Season	5	22.22***	8.72***	41.72***	39.39***	10.53***
Cultivar × N rate	4	0.20	0.23	2.13	0.49	0.32
Cultivar × Season	10	0.08	0.17	1.16	0.37	0.04
N rate × Season	10	0.27	0.03	4.30***	1.38	0.34

*, **, *** - Probability of F-value not exceeding critical F-value less than 0.1, 0.05, and 0.01, respectively.

Table 2. Multiple Comparisons of Mean TRLD and DRLD by Cultivar and Nitrogen Fertility Level

	Total Root Length Density (TRLD)				Deep Root Length Density (DRLD)			
	Nitrogen fertility rate (kg ha^{-1} year^{-1})				Nitrogen fertility rate (kg ha^{-1} year^{-1})			
Cultivar	195.3	390.6	586	LSD ($\alpha = 0.05$)	195.3	390.6	586	LSD ($\alpha = 0.1$)
	root length density (ln cm cm^{-3})				root length density (ln cm cm^{-3})			
Crenshaw	3.30	3.18 A*	3.01	NS	2.55	2.39 A	2.00 A	NS
L93	3.18 a[†]	3.20 Aa	3.04 b	0.10	2.12 b	2.46 Aa	1.92 Ab	0.25
Penncross	3.06	3.03 B	2.89	NS	1.41	1.77 B	1.38 B	NS
LSD ($\alpha = 0.1$)	NS	0.09	NS		NS	0.43	0.43	

* Means in columns followed by different uppercase letters are significantly different.

[†] Means in rows followed by different lowercase letters are significantly different.

influence over every response variable measured. This is not surprising considering mean daily soil and air temperature, on an annual basis, cycle in and out of the optimum range for bentgrass shoot and/or root growth. Therefore, no discussion of seasonal influence will be made. There was no significant difference in TRLD between Crenshaw and L93 under any nitrogen treatment for all seasons combined (Table 2). Both Crenshaw and L93 had significantly greater TRED than Penncross at the medium N rate, there was no difference among the cultivars at the low or high N rate. The greatest TRLD tended to occur at the low and medium nitrogen rates for all cultivars. The highest nitrogen treatment resulted in significantly less TRLD for L93 compared to the low and medium treatments. There were no significant differences in TRLD for Penncross and Crenshaw by nitrogen treatments, however, a decreasing trend of TRLD by increasing N fertility was observed. This suppression in root length probably resulted from nitrogen-induced stimulation of shoot growth. Nitrogen stimulated shoots have priority over roots for carbohydrate reserves. Roots deprived of maintenance levels of carbohydrates will exhibit reduced growth and persistence (6, 34). This negative effect of high N fertility on bentgrass root growth is well substantiated (11, 12).

Deep root length (DRLD), over the entire study, was significantly influenced by cultivar and season only (Tables 1 and 2). For all seasons combined, Crenshaw and L93 had the greatest DRLD at the medium and high treatments compared to Penncross (Table 2). The DRLD of L93 was significantly reduced at the low and high nitrogen rates when compared to the medium. This consistently deeper rooting performance of Crenshaw and L93 are in agreement with their breeding objectives and previous reports (35, 36; VG. Lehman, personal communication, 1998). Increased DRLD of Crenshaw and L93 over Penncross at medium and high N rates may justify their use in new construction, renovation, or inter-seeding of existing turf stands.

Shoot Quality

Shoot quality was significantly affected by cultivar, N rate, and season with significant interaction observed between season and N rate (Table 1). Crenshaw had significantly higher shoot quality at the low nitrogen treatment than either L93 or Penncross. At the medium and high N treatments there was no significant difference between Crenshaw and L93, however, both cultivars had significantly higher shoot quality than Penncross at all N rates (Figure 1). There was no significant difference between the medium and high nitrogen treatments in terms of Crenshaw's shoot quality. Conversely, both L93 and Penncross showed improved shoot quality as nitrogen rates increased from low to medium to high (Figure 1). The lack of Crenshaw's shoot quality response to the highest N treatment suggest that increasing nitrogen rates beyond the medium N rate may

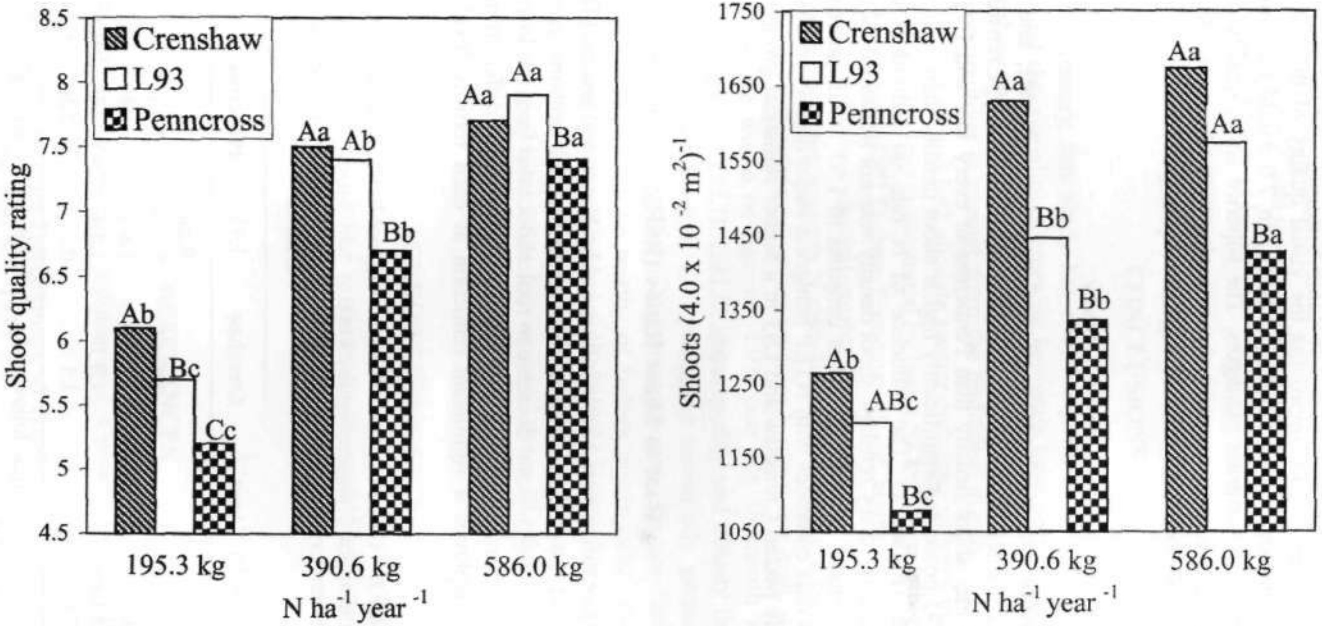

Figure 1. Multiple comparisons of mean shoot quality ratings and shoot densities by cultivar and nitrogen fertility level. Different uppercase letters signify statistical differences between cultivars by N rate ($\alpha = 0.05$, 0.1 for quality rating and density respectively). Different lowercase letters signify statistical differences between N rate by cultivar ($\alpha = 0.01$, 0.1 for quality rating and density respectively).

not be an effective method for improving the visual quality of this cultivar. It should be noted that shoot quality ratings lower than 7.0 would be considered unsatisfactory by most turfgrass managers. The superior shoot quality of these new cultivars suggest they are capable of partitioning more dry matter to below-ground structures without a sacrifice of vegetative quality.

Shoot Density

Shoot density was significantly affected by cultivar, N rate, and season without significant interactions (Table 1). Over the entire study, Crenshaw had significantly greater shoot density than Penncross at every rate and L93 at the medium rate. L93 possessed significantly higher shoot density than Penncross at the high N rate (Figure 1). The influence of N rate on individual cultivar performance indicates that Crenshaw shoot density was not improved by a 380.6 to 586.0 kgN increase, whereas the shoot densities of L93 and Penncross were (Figure 1). This data coincides with NTEP bentgrass shoot density results which have consistently placed Crenshaw and L93 in a higher statistical grouping than Penncross (3).

Root to Shoot Ratios (RSR)

Root to shoot ratios were highly influenced by N rate and season (Table 1). Cultivar type had no influence over this response. All seasons combined, Crenshaw exhibited a significant decrease in root: shoot ratio from the low to high N treatment, but the medium treatment did not significantly differ from either (Table 3). L93 displayed a significant reduction at each fertility level. These

Table 3. Comparisons of Mean Root: Shoot Ratio (RSR) by Cultivar and Nitrogen Fertility Level

	Cultivar		
N Rate ha~^{1} year"^{1}	Crenshaw	L93	Penncross
		Ratio	
195.3 kg	2.5 A*	2.2 A	2.3
390.6 kg	1.7 AB	1.8 B	1.8
586.0kg	1.3 B	1.5 C	1.4
LSD (a = 0.05)	1.1	0.2	NS

*Mean in columns followed by different letters are significantly different.

reductions would be expected since N fertility has been repeatedly shown to increase shoot density and quality at the expense of root growth, especially those of cool season grasses (**11,** 12, 37).

CONCLUSIONS

In summary, this study has shown significant improvements in the root growth and shoot quality of creeping bentgrass have been made with the release of Crenshaw and L93. Although the lack of cultivar effect on root to shoot ratios indicate no cultivar is exempt from the traditional effects of high N fertility, it appears Crenshaw and L93 allocate greater quantities of roots into greater depths of the soil profile. This is illustrated by both L93 and Crenshaw possessing equal TRLD but greater DRLD than Penncross at the highest N rate. Over this 19 month study, Crenshaw showed greater TRLD, DRLD, shoot quality and density than Penncross at the medium N rate. Because the shoot quality and density of Crenshaw did not improve from the medium N rate to the high, it appears that the medium N rate would be optimal. L93, over the 19 month study, possessed significantly greater TRLD, DRLD, shoot quality and density than Penncross at the medium N rate. Overall, L93 possessed statistically greater DRLD at the medium N rate than at the low or high nitrogen rate. This non-traditional response to nitrogen fertility may be worthy of further investigation. Shoot quality and density, however, were maximized at the highest N treatment. Thus, the optimum N fertility rate for L93 may be dependent on how much root performance the turf manager is willing to sacrifice for improved shoot quality.

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