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NITROGEN FORM AND THE SEASONAL ROOT AND SHOOT RESPONSE OF CREEPING BENTGRASS[1]

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ABSTRACT: The form of nitrogen can affect root and shoot growth of plants. This study was conducted to determine the effects of ammonium and nitrate nitrogen on root length and number and shoot color and quality of creeping bentgrass *(Agrostis palustris* Huds. 'Penncross'). The study was conducted in the University of Georgia rhizotron facility. Turf was grown in an 80/20 sand/peat rooting medium and maintained under putting green conditions for 12 months. Two forms of nitrogen, ammonium and nitrate, utilizing the nitrogen sources of urea and calcium nitrate, respectively, were applied in the following ammonium:nitrate ratios: 100:0, 75:25, 50:50, 25:75, and 0:100. A modified Hoagland's solution provided all other macronutrients and micronutrients. Root length, root number, shoot color, and shoot quality data were collected weekly for 12 months. The 100% nitrate treatment resulted in 30% more roots during the fall compared to the 100% ammonium treatment The 100% ammonium treatment had 26% greater root length in the spring compared to the two highest nitrate treatments. The 50:50 treatment produced greater root length during the spring and summer compared to the high nitrate treatments (0:100 and 25:75) and at least

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30% greater root number during the summer compared to all treatments. All treatments resulted in a decrease in root length for the summer compared to the spring. The 50:50 treatment provided higher ratings for shoot color for each season and higher quality ratings for the winter and spring. A fertilizer program that contains a portion of its nitrogen as nitrate would be more beneficial certain times of the year than one containing ammonium or nitrate alone.

INTRODUCTION

Ammonium and nitrate are the main forms of nitrogen that plants utilize. Each form produces different physiological responses within the plant (Cox and Reisenauer, 1973; Haynes and Goh, 1978), and plants vary in dieir capacity to absorb and utilize ammonium and nitrate (Kirkby and Hughes, 1970; Lycklama, 1963). Several studies have reported that turfgrass receiving part or all nitrogen as nitrate produce the greatest amounts of dry matter (Sprague, 1934; Harrison, 1934; Darrow, 1939; Mazur and Hughes, 1976). For example, when Kentucky bluegrass *(Poa pratensis* L.) and colonial bentgrass *(Agrostis tenuis* Sibth.) were treated with ammonium sulfate, calcium nitrate, and sodium nitrate, it was the quantity of ammonium nitrogen that influenced the development of the grasses the greatest (Sprague, 1934). Increasing the ammonium sulfate level caused the dry matter to decrease in both bentgrass (26%) and Kentucky bluegrass (46%). The addition of sodium nitrate to a treatment containing both ammonium and nitrate stimulated bentgrass growth, while additions of ammonium sulfate to the ammonium and nitrate treatment decreased growth. Harrison (1934) utilized calcium nitrate and ammonium sulfate to compare the effects of a high ammonium-low nitrate fertilizer to a low ammonium-high nitrate fertilizer on Kentucky bluegrass. He reported that the high nitrate mixture yielded 22% more root and 42% more rhizome dry weight Darrow (1939) found that nitrate-treated Kentucky bluegrass plants yielded greater leaf, rhizome, and root growth than did ammonium-treated plants. Mazur and Hughes (1976) found seasonal differences in shoot growth among nitrate ($Ca(N0_3)2$), ammonium (urea), and nitrate +

ammonium nitrogen fertilizer sources utilized on creeping bentgrass. Nitrate alone provided maximum shoot growth in the spring, while ammonium and nitrate together provided the maximum shoot growth during the summer and fall.

Similarly, several investigators have reported differences in root growth when turfgrasses were treated with various ratios of ammonium and nitrate. Eggens and Wright (1985) treated annual bluegrass *(Poa annua* L.) and creeping bentgrass grown in monostands and polystands with various ratios of ammonium and nitrate. At the two highest ammonium treatments, the bentgrass monostand yielded the least root dry matter, while the high nitrate treatment yielded the greatest root dry matter. Annual bluegrass decreased 23%, 41%, and 33% in shoot dry weight, root dry weight, and tiller number, respectively, when the 100% ammonium treatment was compared to the 0% ammonium treatment. In a greenhouse study, Glinski et al. (1990) reported a 56% increase in root mass for creeping bentgrass grown under high nitrate treatments compared to high ammonium treatments. Although root mass and root lengths increased at the higher nitrate levels, the plants treated with higher ammonium levels produced darker green shoots.

Very few studies have investigated the long-term effects of nitrogen form on the root growth of creeping bentgrass. Most work has involved short-term greenhouse or field studies that concentrated on shoot growth. Creeping bentgrass, often utilized on putting greens in the southeastern United States, depends upon an extensive and healthy root system for its survival. Thus, it is important to understand how nitrogen fertility affects its overall growth, particularly root growth. Therefore, the purpose of this study was to determine the effect of ammonium and nitrate in various ratios on the seasonal root growth and shoot quality of creeping bentgrass.

MATERIALS AND METHODS

The study was conducted in the rhizotron facility at the University of Georgia from May 1988 through December 1989. The experiment utilized 15 rhizotron chambers that measured 1 by 0.5 by 1.85 m deep. Each individual chamber contained a tempered-glass viewing area of 0.5 by 1.85 m positioned at a 12.5° angle from the vertical.

Chamber Preparation: A wire screen was placed over a 15-cm diameter drainage hole at the bottom of each chamber and coarse gravel was placed in the lower 5 cm of each chamber. Sand, ranging in particle size from 0.50 to 2.00 mm, was placed over the coarse gravel layer for the next 124 cm of each chamber. At 15-cm increments, the soil was compacted evenly and bulk density was taken with a Troxler Model 341 IB Moisture Density Gauge (Troxler Laboratories, Research Triangle Park, NC) and maintained between 1.30 to 1.40 g cm'[3]. Layering between the increments was avoided by lightly scratching the top 2 cm of each increment with a rake prior to the addition of the next increment. The remainder of each chamber was constructed to adhere to the putting green specifications as defined by the USGA (Bengeyfield, 1989). A 10-cm layer of pea gravel was placed on top of the sand, followed by another 5-cm layer of sand. A root zone medium composed of a mixture of 80% quartz sand and 20% Michigan peat was placed in the upper 36-cm portion of each chamber, as described above. The quartz sand had the following particle size distribution: < 0.10 mm, 0.8%; 0.10 to 0.25 mm, 7.0%; 0.25 to 0.50 mm, 40.0%; 0.50 to 1.00 mm, 51.2%; and > 1.00 mm, 1.0%.

Plantine and Treatment Application: **On 17 May** 1988, 'Penncross' creeping bentgrass sod was cut from an established green at the University of Georgia turfgrass demonstration plots. Soil was washed from the roots. Sod was laid the next day on the individual 0.5 m^2 plots. Strips of sod were placed around the plots to form a 1.5-m wide border. The plots were fertilized with a modified Hoagland's solution through August at the rate of 454 g N 92.9 m'[2] split over two monthly applications. Calcium nitrate was utilized as the sole nitrogen source. Beginning in September 1988, treatments were applied as ammonium:nitrate expressed in percentage ratios as follows: 100:0, 75:25, 50:50, 25:75, and 0:100. Urea and calcium nitrate were the ammonium and nitrate sources, respectively.

Treatments were applied at the following monthly rates (g N 92.9 m^{-2}): September, 681; October, 454; November, 454; December, 454; January, 227; February, 227; March, 454; April, 681; May, 1362; June, 908; July, 454; August, 227; September, 908. All other macronutrients and micronutrients were supplied in a modified Hoagland's solution that was applied each time treatments were applied. All treatments were applied in split applications twice monthly.

Plot Maintenance: A preventative fungicide program was established utilizing chlorothalonil (tetrachloroisophthalonitrile), iprodione [3-(3,5-dichlorophenyl)-N-(l-methylethyl)2,4-dioxo-l-imidazolidinecarboxamide], metalaxyl [N-(2,6-dimethylphenyl)-N-(methoxyacetyl)-alanine methyl ester], and propamocarb hydrochloride {propyl [3-(dimethylamino) propyl] carbamate monohydrochloride} applied at recommended rates (Brown, 1988). Trichlorfon [dimethyl (2,2,2-trichloro-1-hydroxyethyl) phosphonate] was applied at recommended rates for white grub control as needed (Brown, 1988). The turfgrass was irrigated to prevent wilting. Plots were top-dressed with 2-4 mm of the root zone mix in May and June 1988, and March and September 1989. The plots were mowed daily and maintained at 0.5 to 0.8 cm except for heat stress periods during the summer and periods of slow growth during the winter, when the turf was mowed three or four times weekly at a height of 1.0 to 1.5 cm.

Shoot and Root Observations: Visual ratings for shoot color and quality were made weekly for each plot. Turfgrass color was measured on a scale in which 1 = brown and 10 = dark green turfgrass. Quality was measured on a scale in which 1 = no live grass and 10 = a dense, uniform stand of turf.

Roots were observed though a viewing area, 5 by 50 cm, that was located in the center of the viewing window. Root observations were made weekly from 22 September 1988 through 22 September 1989. A 4-mm thick sheet of Trans-Art Trans-Stay clear polyester (Transilwrap Company of Atlanta, Inc., Atlanta, GA) was placed on the viewing area and a long wave ultra-violet radiation (320 to 400 nm) light (Model B-100A/R Blak-Ray Ultra-Violet Lamp, UVP, Inc., San Gabriel, CA) was used to induce root fluorescence. Roots that fluoresced were considered live and actively growing (Goodwin and Kavanagh, 1948; Dyer and Brown, 1983) Individual roots in the viewing area were traced onto the polyester sheets. Utilizing the root tracings, root length was determined at 5-cm increments using a digital linear probe (Lasico Model M Processor with a Model 71A Linear Measuring Probe attached, Los Angeles Scientific Co., Los Angeles, CA). Root number was recorded weekly by counting the traced roots that had been initiated since the previous week. Root and shoot data presented for the seasons were for 13-week seasons defined as follows: Fall, 22 September to 20 December 1988; Winter, 21 December 1988 to 19 March 1989; Spring, 20 March 1989 to 20 June 1989; and Summer, 21 June 1989 to 22 September 1989.

The experimental design was completely randomized with three replications of each nitrogen treatment. Analysis of variance was by the General Linear Model (GLM) procedure of Statistical Analysis System (SAS Institute, 1987). Mean separation was by the LSD method of Statistical Analysis System (SAS Institute, **1987).**

RESULTS AND DISCUSSION

Seasonal Root Growth

Fall: No significant differences among treatments for mean root length occurred during the first season of the study (Table 1). The 0:100 treatment produced a greater number of roots than did the 100:0 treatment (Table 2). There were 30% more roots for the 0:100 treatment compared to the 100:0 treatment. The only significant differences for root length within depth groups were at the 0- to 15- and 30- to 45-cm depths (Table 3). At 0 to 15 cm, the high nitrate treatment (0:100) had 46% more root length than had the high ammonium treatment (100:0). The 100:0 treatment produced the greatest root length at the 30- to 45-cm depth.

The reduced root number during the initial applications of the ammonium treatments may have been caused by the known detrimental effects of ammonium on roots not yet acclimated to ammonium (Barker et al., 1966; Lewis et al., 1983; Rufty et al., 1982). Thus, there would be less root growth since the high

TABLE 1. Effect of N-form Ratio on Seasonal Mean Total Root Length of Creeping Bentgrass.

	Season				
$NH_4^+:NO_3^-$ ratio	Fall	Winter	Spring	Summer	Total
			root length (cm)		
100:0	**229.1**	**200.1**	**281.5 a**	**113.5 b**	**824.2**
75:25	**256.6**	**217.8**	**259.0 ab**	**116.1 ab**	**849.5**
50:50	**278.9**	**225.9**	**254.2 ab**	**141.9 a**	**900.9**
25:75	**264.3**	**229.0**	**223.6 b**	**96.5 b**	**813.4**
0:100	**290.0**	**184.6**	**223.4 b**	**105.3 b**	**803.3**
LSD a=0.10	**NS**	**NS**	**56.7**	**27.2**	**NS**

Means witnin columns followed by the same letter are not significantly different according to LSD mean separation test at a =0.10.

ammonium-treated plants had fewer roots and restricted root branching (Bennett et al., 1964; Glinski et al., 1990; Schrader et al., 1972).

Winter: Root length showed a significant decrease from fall to winter for the 50:50 and 0:100 treatments (Table 4). There was a 23% decrease in root length with the 50:50 treatment and a 57% decrease in root length with the 0:100 treatment from the fall to the winter.

No significant differences for root length (Table 1) or root number (Table 2) occurred among treatments during the winter. Root length differed significantly between the 25:75 and 100:0 treatments at the depth group of 15 to 30 cm (Table 3). At the 0- to 15-cm depth, there were decreases in root length among treatments when compared to lengths in the fall These decreases in root length ranged from 182% to 274% for the 100:0 and 0:100 treatments, respectively. In contrast, there were increases in root length at the other two depths.

The optimum soil temperature range for maximum sustained root growth for cool season grasses is 10° to 18° C (Beard, 1973). Root growth of creeping

TABLE 2. Effect of N-form Ratio on Seasonal Mean Total Root Number of Creeping Bentgrass.

$NH_4^+:NO_3^-$ ratio	Fall	Winter	Spring	Summer	Total
100:0	312 b	312	421	210 b	1255 b
75:25	344 ab	353	420	213 b	1330 ab
50:50	379 ab	401	403	276 a	1459 a
25:75	354 ab	380	372	198 b	1304 ab
0:100	406a	325	369	213 b	1313 ab
LSD a =0.10	73	NS	NS	53	187

Means within columns followed by the same letter are not significantly different according to LSD mean separation test at *a* - 0.10.

bentgrass decreases as soil temperatures either increase or decrease from the optimum and is minimal at 0° C (Beard, 1973; Beard and Daniel, 1965). The minimum and maximum soil temperatures at a depth of 10 cm for the winter were 7.9° and 13.2° C, respectively (Table 5). Brown (1943), investigating Kentucky bluegrass over different seasons, found that the average maximum temperature was lower and the average minimum temperature was higher as depth increased below the surface. Stuckey (1941), working with a variety of cool season grasses, reported that root growth could occur at temperatures approaching 0° C but that extensive root elongation generally did not occur below this temperature. Thus, in the present study, the root length was greatest for all treatments at the 15- to 30-cm depth. This effect was probably caused by the slightly higher and more stable soil temperatures at this depth that were not affected as much by ambient air temperatures, as would be the case for the 0- to 15-cm depth.

Spring: The 100:0 treatment produced a significantly greater increase in root length (41%) from winter to spring, although the other treatments tended to exhibit

TABLE 3. Effect of N-form Ratio on Mean Root Length of Creeping Bentgrass for Seasons by Depth Groups.

NH_4^+: NO_3^- ratio	Fall	Winter	Spring	Summer	Total
		Depth: 0 to 15 cmHI			
100:0	154.1 b	54.7	403	30.4	279.7 c
75:25	191.9 ab	55.4	50.7	35.8	333.8 ab
50:50	169.9 b	53.2	43.0	311	298.2 bc
25:75	194.3 ab	511	443	28.0	3189 bc
0:100	225.3 a	603	503	35.0	370.9 a
LSD a =0.10	41.5	NS	NS	NS	50.4
		Depth: 15 to 30 wu			
100:0	69.0	100.5 b	1573	513 b	378.5 b
75:25	63.5	126.0 ab	161.4	47.5 b	,398.4 b
50:50	106.0	134.8 ab	142.1	74.9 a	457.8 a
25:75	68.7	159.7 a	142.3	53.2 b	423.9 ab
0:100	64.7	110.1 ab	1553	59.9 ab	390.2 b
LSD a =0.10	NS	59.1	NS	20.2	47.6
		Depth: 30 to 45 MU			
100:0	6.0 a	44.9	833 a	31.6 ab	166.0 a
75:25	1.2 ab	36.4	46.9 abc	32.8 ab	117.3 abc
50:50	3.0 ab	37.9	69.1 ab	35.9 a	145.9 ab
25:75	13 ab	17.2	36.8 be	153 be	70.6 be
0:100	0.0 b	14.2	17.6 c	10.4 c	412 c
LSD a =0.10	5.5	NS	42.8	19.4	90.7

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greater root lengths with the change of seasons (Table 4). The high ammonium treatment (100:0) produced a significantly greater root length than did the high nitrate treatments (0:100 and 25:75) in the spring (Table 1). Twenty-six percent more root length occurred with the 100:0 treatment compared to the 0:100

TABLE 4. Effect of Season Within N-form Treatment on Mean Total Root Length of Creeping Bentgrass.

	NH_4^+:NO_3^- ratio				
Season	100:0	75:25	50:50	25:75	0:100
	root length (cm)				
Fall	229.1 ab	256.6 a	278.9 a	264.3 a	290.0 a
Winter	200.1 b	217.8 ab	225.9 b	229.0 a	184.6 b
Spring	281.5 a	259.0 a	254.2 ab	223.6 a	223.4 ab
Summer	113.5 c	116.1 c	141.9 c	96.5 b	105.3 c
LSD α=0.10	61.6	77.4	47.1	57.0	76.1

Means within columns followed by the same letter are not significantly different according to LSD mean separation test at α = 0.10.

TABLE 5. Seasonal Average Mean, Minimum, and Maximum Soil (10 cm depth) and Ambient Air Temperatures.

	Soil			Air		
Season	Mean	Minimum	Maximum	Mean	Minimum	Maximum
	°C					
Fall	13.9	11.2	17.0	11.9	5.8	19.7
Winter	10.3	7.9	13.2	10.4	5.0	16.6
Spring	19.4	16.4	22.6	22.0	21.0	23.2
Summer	27.8	25.2	30.9	26.7	25.8	27.7

treatment, while there was no difference in the number of roots (Table 2). The 100:0 treatment produced significantly greater root length at the 30- to 45-cm depth compared to the 0:100 and 25:75 treatments (Table 3). At this depth, the 100:0 treatment had 374% more root length than had the 0:100 treatment. During April and May, the 100:0 treatment produced significantly greater root lengths

TABLE 6. Effect of N-form Ratio on Mean Monthly Root Length of Creeping Bentgrass for the Months of April through September.

	NH_4^+:NO_3^- ratio					
Month	100:0	75:25	50:50	25:75	0:100	LSD
	root length (cm)					
April	82.5 a	69.5 ab	68.9 ab	66.8 ab	56.1 b	16.6
May	68.9 a	57.9 ab	53.2 b	43.5 b	43.2 b	15.6
June	135.4	151.4	141.4	125.6	140.1	NS
July	61.0 ab	59.4 bc	76.3 a	44.8 c	52.7 bc	15.8
August	21.4 ab	16.3 b	26.3 a	19.4 b	17.8 b	5.5
September	11.4 ab	7.9 b	13.9 a	10.4 ab	8.63 b	3.9

LSD mean separation test at a = 0.10.

compared to the 0:100 treatment (Table 6). This increased root growth is consistent with data reported by others in which the greatest root initiation took place during spring and fall for cool season grasses (Beard and Daniel, 1965; Powell et al., 1967). Darrow (1939) reported deeper root systems for both ammonium- and nitrate-treated Kentucky bluegrass plants at temperatures of 15° and 25° C compared to 35° C. Soil temperatures during the spring (Table 5) were close to the optimum soil temperatures for root growth of cool season grasses (Beard, 1973).

<u>Summer:</u> All treatments showed a significant decrease in root length from spring to summer with the percentage decrease for each treatment as follows: 100:0, 148%; 75:25,123%; 50:50,79%; 25:75,132%; and 0:100,112% (Table 4). Most root initiation and growth for cool season grasses takes place in the spring and fall (Sprague, 1933; Stuckey, 1941; Beard and Daniel, 1965; Powell et al., 1967). In contrast, very little root growth occurs during the summer months (Stuckey, 1941; Beard and Daniel, 1965, 1966).

Soil temperatures were substantially higher during the summer months compared to the spring (Table 5). The summer maximum and minimum soil temperatures were 30.9° and 25.2°C, respectively, while the summer mean soil temperature was 27.8°C, which is higher than the reported optimum soil temperatures for cool season grasses of 18°C (Beard, 1973). Beard and Darnel (1966) working with creeping bentgrass found most root initiation and elongation occurred in the spring. They found that new root elongation in the summer rarely occurred, except during times of decreased soQ temperatures. Others have reported reduced root growth for Kentucky bluegrass treated with both ammonium and nitrate at a soil temperature of 35°C compared to soil temperatures of 15° and 25°C (Harrison, 1934; Darrow, 1939).

During the summer, the 50:50 treatment produced greater root length compared to the high nitrate treatments (25:75 and 0:100) and the high ammonium treatment of 100:0 (Table 1). In addition, the 50:50 treatment produced greater root numbers compared to all treatments (Table 2). During the months of July, August, and September the 50:50 treatment had significantly greater root lengths than most of the other treatments (Table 6). The 50:50 treatment had the greatest mean root length at both the 15 to 30 and 30 to 45 cm depth groups (Table 3). At depths of 30 to 45 cm, the high ammonium treatments (100:0 and 75:25) and the 50:50 treatment produced significantly greater root lengths compared to the high nitrate treatment (0:100).

Total Root Growth!

No statistical differences among treatments occurred for total mean root length over 12 months (Table 1). Less than a 2% difference in the total mean root lengths occurred between the treatment extremes of 100:0 and 0:100. The 50:50 treatment produced significantly greater root numbers compared to the 100:0 treatment (Table 2).

Significant differences among treatments for total root length occurred at each of the three depth groups (Table 3). At the 0 to 15 cm depth, the 0:100 treatment produced 33% more total root length than the 100:0 treatment The 50:50 treatment had the greatest total root length at the 15 to 30 cm depth compared to the other treatments. At the lowest depth of 30 to 45 cm, the high ammonium treatment produced significantly greater total root length compared to the high nitrate treatment. Total root length for the 100:0 treatment was 293% greater than the length for the 0:100 treatment at the lowest depth. Compared to the 0:100 treatment, the 100:0 treatment consistently had greater root lengths at the 30 to 45 cm depth throughout the seasons. The 100:0 treatment had 20% of its total root length within the 30 to 45 cm while the 0:100 treatment had only 5% of its total root length at this depth. This suggests that N-form may affect the depth of rooting and ammonium may provide a deeper root system in creeping bentgrass over time. There is no explanation for this phenomenon and it deserves further study.

Under the conditions of this study, the data indicated that a combination of ammonium and nitrate is preferable in order to provide the greatest root length and number for creeping bentgrass. This is consistent with other studies in which the two N-fonns utilized in different ratios provided greater root growth compared to plants grown with only ammonium (Bennett et al., 1964; Bowman and Paul, 1988; Eggens and Wright, 1985; Glinski et aL, 1990). Bennett et al. (1964) reported that nitrate alone and a combination of ammonium and nitrate provided the greatest root dry weights in corn *(Zea mays* L). They concluded that the overall root including root branching, was reduced by me ammonium treatment compared to the nitrate and ammonium-plus-nitrate treatments. Bowman and Paul (1988) found that ammonium inhibited perennial ryegrass *{Lolium perenne* L.) root growth but nitrate did not. Several investigators have reported high nitrate treatments yielded more root dry matter than did high ammonium treatments for creeping bentgrass (Eggens and Wright, 1985; Glinski et al., 1990).

Glinski et al. (1990) found that a 1:1 ratio of ammonium to nitrate provided the greatest root length for creeping bentgrass and high ammonium treatments (1:0 and 3:1) provided the least In contrast to their 3:1 treatment which resulted in the second lowest root length, the 75:25 treatment in the present study provided the second greatest overall root length. However, the 75:25 treatment yielded the second and third lowest root lengths during the fall and winter, respectively. The present study found no significant differences between total root length between the high ammonium and high nitrate treatments over the course of the entire study, but Glinski et al. (1990) reported differences between the 1:0 and 0:1 treatments. The differences between the two studies may be due to the length and conditions of each study. The 1990 study investigated N-form effects on sodded bentgrass for only a 37-day period under day/night temperatures of 20/25°C, while the present study was conducted for 12 months under a much wider range of temperatures and environmental conditions. The initial effect of the high ammonium treatments in the present study was to produce fewer and shorter roots, but as the study continued that effect did not manifest itself over time.

Shoot Responses

Color: The 50:50 treatment had significantly higher ratings for shoot color during each season compared to all other treatments (Table 7). Shoot color ratings with this treatment were highest for each of the 12 months and were significantly different from all treatments for 7 of the 12 months. No significant differences between the high ammonium and high nitrate treatments occurred, except for the spring when the 100:0 treatment had a significantly higher color rating. The spring color response was similar to that reported by Glinski et al. (1990). They found that an ammonium-only treatment of creeping bentgrass produced the greenest plants, while a nitrate-only treatment produced the lightest green color compared to several ammonium:nitrate ratios. Others have also found that N-form affects turfgrass color (Harrison, 1934; Nittler and Kenny, 1976).

Quality: The 50:50 treatment had the highest quality ratings for winter and

TABLE 7. Effect of N-forra Ratio on Seasonal Mean Shoot Color and Quality of Creeping Bentgrass.

	Season							
$NH_4^+:NO_3^-$ ratio	Fall		Winter		Spring		Summer	
	Color	Quality	Color	Quality	Color	Quality	Color	Quality
100:0	5.7 b	5.9 ab	4.9 b	5.1 b	6.6 b	6.4 b	6.6 b	6.6 ab
75:25	5.6 b	5.6 b	4.9 b	5.1 b	6.5 bc	6.2 b	6.4 bc	6.4 bc
50:50	6.3 a	6.2 a	5.8 a	5.9 a	7.2 a	7.1 a	6.9 a	6.8 a
25:75	5.5 b	5.8 b	5.2 b	5.2 b	6.4 bc	6.3 b	6.3 c	6.3 c
0:100	5.6 b	5.8 b	5.1 b	5.2 b	6.2 c	6.3 b	6.4 bc	6.3 bc
LSD $\alpha=0.05$	0.2	0.3	0.4	0.3	0.3	0.3	0.2	0.2

Means within columns followed by the same letter are not significantly different according to LSD mean separation test; $\alpha = 0.05$. (10=dark green; 1=brown)

spring and the highest quality ratings compared to the other treatments for 5 of the 12 months of the study (Table 7). There were no significant differences between the high ammonium and high nitrate treatments for any season.

The 50:50 treatment provided the best shoot color and quality of any of the treatments over the entire study. Generally, the high ammonium treatment tended to result in slightly better color and quality than did the high nitrate treatment during the spring and summer, while the high nitrate applications tended to provide higher color and quality ratings in the winter. An increase in both color and quality occurred in the spring for all treatments. The improved color and quality continued for some treatments into the summer months. These increases in color and quality ratings during this time of the year may be caused by the response to the increased amount of nitrogen applied in April, May, and June.

CONCLUSIONS

The high nitrate treatment (0:100) yielded the greatest number of roots in the fall, which was a period of root establishment under the initial treatment applications. The form of nitrogen may be important in the initial establishment of the root system of new bentgrass sod. Since ammonium has been found to cause root injury in a variety of plants, it is possible that initially the high ammonium treatment inhibited root growth. The inhibition was relieved when those turfgrass plants receiving ammonium became acclimated to the ammonium.

This work confirms the research of others who have found differences for shoot and root growth of turfgrass grown under different ratios of ammonium and nitrate. They reported that the best overall root and shoot growth is provided by a combination of the two N-forms, not by applications of ammonium or nitrate alone. In the present study, the high ammonium treatments provided adequate shoot color and quality but decreased the number of roots. The ratios of 50:50 or 75:25 ammonium to nitrate resulted in the highest number of roots and the best quality of shoots over the entire study. Since many of the fertilizers utilized in the turfgrass industry are ammonium or urea-based, this study suggests that a fertilizer that does not include nitrate would not provide the best growth over an entire year. The high ammonium treatment provided the greatest root lengths during the spring, while the 50:50 treatment provided greater root length and number during the summer. Therefore, a fertilizer that includes a portion of its nitrogen as nitrate would benefit turfgrass growth during the change of seasons from spring to summer.

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