USGA REGIONAL PROJECT

PROJECT TITLE

Defining Optimal and Deficient Annual Nitrogen Fertility Rates for a *Poa annua*-Creeping Bentgrass Putting Green in California

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SUMMARY

Results from this study show that optimal and deficient annual N fertility rates for *Poa annua*-creeping bentgrass putting greens in California probably range from 6.0 to 3.0 lb/1000 ft^2, respectively. This range would be a general guide, keeping in mind that annual N fertility rates may need to be adjusted depending on several factors, such as: amount of play; soil type; salinity and leaching requirements; amount of rainfall; irrigation with recycled water; N application schedule, rates, and N sources; Fe and plant growth regulator applications; turfgrass quality and color expectations; green speed expectations; and others.

Lower annual N fertility rates resulted in significantly lower: visual turfgrass quality and color; clipping yield; recovery from core cultivations; and shoot density. There also a non-significant trend that lower annual N fertility rates resulted in more *Rhizoctonia* brown patch coverage along with lower seedhead coverage.

RATIONALE/DESCRIPTION OF PROBLEM

Most golf course superintendents in California are managing *Poa annua* as their putting green turf. The major reason for this norm is the relatively mild climate of the region which usually results in newly established creeping bentgrass putting greens converting to *Poa annua* putting greens in 5 to 7 years. An exception to this rule is the warmer desert locations, such as Palm Springs, where bermudagrass and, less frequently, creeping bentgrass putting greens are maintained. The major problems of managing *Poa annua* putting greens include: summer decline, which includes several issues, such as high temperatures, disease activity, traffic, and salinity; seedhead production, especially during the spring; and puffiness during the growing season (October through late December and February through June). In many other regions of the USA, *Poa annua* encroachment into creeping bentgrass putting greens can be controlled. Thus, considerable research has been and continues to be on managing creeping bentgrass putting greens rather than on managing *Poa annua* putting greens.

The annual N fertility rates that have been tested on *Poa annua* grown in the field vary considerably. Goss et al. (1975) tested N rates of 6.0, 12.0, and 20.0 lb/1000 ft^2; Engel (1974) tested N rates of 4.0 and 8.0 lb/1000 ft^2; Dest and Guillard (1987) tested N rates of 2.0 to 2.5 lb/1000 ft^2; Dest and Allinson (1981) tested N rates of 3.0 lb/1000 ft^2; and Gaussoin and Branham (1989) tested N rates of 2.0 and 6.0 lb/1000 ft^2. It should be noted that factors such as the length of growing season and amount of rainfall can affect recommendations concerning annual N fertility rates.

In a relatively recent GCSAA/CGCSA Chapter Cooperative Research Program study, Green et al. (2001) tested annual N fertility rates of 6.0 and 11.0 lb/1000 ft^2 on an in-use *Poa annua* putting green in southern California and reported that the lower rate was close to optimal in terms of: visual turfgrass quality and color ratings; coverage of seedheads, mottling and patchiness, disease activity, leaf wilting and rolling, and scalping; root and crown mass; and concentration of total N in clipping tissue. The lower N rate ranged from 4.24% to 5.81% total N in clipping tissue which is basically within the published target range of 4.5% to 6.0% for creeping bentgrass.

Since there is a trend for golf course superintendents to apply less N on *Poa annua* putting greens, it would be useful to evaluate the lower range of annual N fertility rates. These data could be combined with other data concerning optimal annual N fertility rates, so that golf course superintendents in southern California could be offered a range of optimal, sufficient, and deficient rates. This information could serve as a general guide, keeping in mind that N rates may need to be adjusted depending on such factors as: amount of play; soil type; salinity and leaching requirements; amount of rainfall; irrigation with recycled water; N application schedule, rates, and N sources; Fe and plant growth regulator applications; and others.

OBJECTIVES

Annual N fertility rates, ranging from 1.5 to 5.5 lb/1000 ft^2, were evaluated for 2 years on a *Poa annua*-creeping bentgrass putting green nursery. Irrigation with recycled water supplied an annual N fertility rate of approximately 0.5 lb/1000 ft^2. During the study, levels of P, K, and Fe were maintained at commonly-practiced levels.

MATERIAL AND METHODS

Location. The location of this study was an 8,500 ft^2 mature *Poa annua*-creeping bentgrass nursery located at Industry Hills Golf Club at Pacific Palms Conference Resort, City of Industry, California. The majority of the nursery was covered with *Poa annua,* especially during the cool season. The nursery was established in November 1997 by planting cores of *Poa annua* and seeding creeping bentgrass on to an 11-inch deep sand rootzone which was constructed with sand that met USGA specifications. The nursery did not have a drainage system. It was irrigated with recycled water which had the following most-recent, 2-year average N concentrations at the water treatment plant: 1.6 ppm ammonia N; 1.4 ppm organic N; 3.9 ppm nitrate N; and 0.08 ppm nitrite N (6.98 ppm total N). Based on previous work at this golf course, irrigation of putting greens supplies an annual N fertility rate of approximately 0.5 lb/1000 ft^2. Selected results of a soil test taken on 6 Apr. 2005, prior to application of annual N fertility-rate treatments, showed: pH = 6.8; Sodium Absorption Ratio (SAR) = 2 (low); Exchangeable Sodium Percentage (ESP) = 2% (low); extractable Fe = 14.9 ppm (sufficient); Cation Exchange Capacity (CEC) = 2.3 meq/100 g (low); Organic Matter (OM) = 0.80% (low); Olsen-P = 7.2 ppm (low); exchangeable K= 64 ppm (low); exchangeable Ca = 602 ppm (sufficient); exchangeable Mg = 69 ppm (low); exchangeable Na = 52 ppm; and 93%, 5%, and 2% sand, silt, and clay, respectively.

Treatments. The four annual N fertility-rate treatments (1.5, 2.8, 4.2, and 5.5 lb/1000 ft^2) (Table 1 and Fig. 1) were arranged in a randomized complete block design with three replications. Individual plot size was 6.0 x 11.0 ft with 1.0- or 3.0-ft borders between plots. Nitrogen fertility-rate treatments were spray applied once every 3 weeks. The first N fertility-rate treatment application was 13 Apr. 2005 and the last application was 25 Apr. 2007. Table 1 also shows how P and K were applied to maintain sufficient and representative nutrient levels. It also should be

noted that Fe (2 oz ferrous sulfate/1000 ft^2) was tanked mixed with Primo (0.125 oz Primo Maxx/1000 ft^2) and applied once every 2 weeks.

Measurements. Starting June 2005, visual turfgrass quality and color ratings were taken every 4 to 6 weeks. Visual turfgrass quality was rated on a 1 to 9 scale, with 1=worst, 5=minimally acceptable, and 9=best putting green and visual turfgrass color was rated on a 1 to 9 scale, with 1=brown, 5=minimally acceptable, and 9=darkest green putting green. Visual ratings of disease activity coverage (0% to 100%), *Poa annua* seedhead coverage (0% to 100%), and recovery from core cultivations (0% to 100% ground cover) also were taken. Measurements of clipping yields; concentration of total N, P, and K in clipping tissue; and 2-day plant uptake of N, P, and K were measured in July, October, January, and April. Two-day growth from 40.3 ft^2 of each plot was collected with the same mower used for routine mowing, dried in a forced-air oven, and weighed. Data are reported as g/m^2 per day. Clipping tissue was ground and then sent to the University of California, Davis Analytical Laboratory for analysis and determination of concentration of total N, P, and K in clipping tissue. Calculations involving the above data were made to determine plant uptake of N, P, and K which are reported as g/m^2 per day. At the end of the 2-year study, cores were taken to measure shoot density and root mass density. Three 2.13-inch diameter cores were taken from each plot. Each core was separated into three sections: a cut at the thatch-soil interface which was approximately 0.37-inch deep from the surface; a cut 3 inches deeper from the previous cut; and a cut 3 inches deeper from the previous cut. The same three sections from each plot were pooled into a plastic bag. Bags were taken back to the laboratory and placed into a freezer until analysis. The upper sections were used to determine shoot density while the other sections were used to determine root mass density in the 0- to 3-inch and 3- to 6-inch root-depth zone. Following the appropriate calculations, shoot density is reported as shoots/cm^2 and root mass density is reported as mg/cm^3. Soil analyses for total N, Olsen-P, and exchangeable K, Ca, Mg, and Na were taken 1 and 2 years following N fertility-rate treatment initiation. Soil samples from the three replicate plots of each annual N fertility-rate treatment were pooled into one bag.

Plot management. Starting in April 2005, the nursery was maintained in exactly the same way as other greens on the golf course. The details of the plot management are shown in Table 2.

RESULTS

Visual turfgrass quality and color. All annual N fertility-rate treatments provided satisfactory visual turfgrass quality and color (Tables 3 and 4 and Figs. 2 to 4). In terms of annual N fertility-rate treatments (lb/1000 ft^2): 5.5 > 4.2 > 2.8 and 1.5. If the additional N supplied in irrigation (approximately 0.5 lb/1000 ft^2 per year) is included, then, in terms of annual N fertility-rate treatments (lb/1000 ft^2): 6.0 > 4.7 > 3.3 and 2.0. It is probable that the optimal and deficient annual N fertility rates range from 6.0 to 3.0 lb/1000 ft^2, respectively. This range would be a general guide, keeping in mind that annual N fertility rates may need to be adjusted depending on several factors, such as: amount of play; soil type; salinity and leaching requirements; amount of rainfall; irrigation with recycled water; N application schedule, rates, and N sources; Fe and plant growth regulator applications; turfgrass quality and color expectations; green speed expectations; and others.

Disease incidence and Poa annua seedhead development. During December 2005, there was an outbreak of *Rhizoctonia* brown patch. Ratings showed a non-significant trend that as annual N fertility rates increased, the coverage of *Rhizoctonia* brown patch decreased (Table 5 and Fig. 5). Ratings of *Poa annua* seedhead coverage showed a non-significant trend that as annual N fertility

rates increased, the coverage of seedheads also increased (Table 7 and Fig. 7). It is possible that the lower annual N fertility rates resulted in insufficient growth potential to produce relatively high seedhead coverage.

Clipping yield and recovery from core cultivation. Clipping yield was significantly affected by annual N fertility-rate treatments (Table 8 and Figs. 8 and 9). In terms of the overall effect of annual N fertility-rate treatments (lb/1000 ft^2): 5.5 > 4.2 > 2.8 and 1.5. If the additional N supplied in irrigation (approximately 0.5 lb/1000 ft^2 per year) is included, then, in terms of the overall effect of annual N fertility-rate treatments (lb/1000 ft^2): 6.0 > 4.7 > 3.3 and 2.0. Clipping yield also was affected by season, with the lowest yield during January. During the second year, the 1.5 lb/1000 ft^2 annual N fertility- rate treatment had less than 50% recovery from core cultivations compared to the other annual N fertility-rate treatments (Table 6 and Fig. 6). This observation was expected since lower annual N fertility rates resulted in slower growth.

Concentration of total N, K, and P in clipping tissue. On selected dates, there were significant differences among annual N fertility-rate treatments for N and K concentrations (Table 8 and Figs. 10 and 12).Concentrations of N and K were within published target sufficiency ranges for creeping bentgrass, except during January. There were no significant differences among annual N fertility- rate treatments for P concentrations (Table 8 and Fig. 11).Concentrations of P varied by date, but remained within the published target sufficiency ranges for creeping bentgrass.

Shoot and root mass density. At the end of the study, cores were taken to measure shoot and root mass density. Results showed that higher annual N fertility rates resulted in significantly higher shoot densities (Table 10). This result was expected since higher annual N fertility rates resulted in more growth. Results also showed that annual N fertility rates did not affect root mass density in either the 0- to 3-inch nor 3- to 6-inch root-depth zone (Table 10). It should be noted that the expectation was that lower annual N fertility rates would have resulted in lower root mass densities due to insufficient growth.

CONCLUSIONS

Results from this study show that optimal and deficient annual N fertility rates for *Poa annua*-creeping bentgrass putting greens in California probably range from 6.0 to 3.0 lb/1000 ft^2, respectively. This range would be a general guide, keeping in mind that annual N fertility rates may need to be adjusted depending on several factors, such as: amount of play; soil type; salinity and leaching requirements; amount of rainfall; irrigation with recycled water; N application schedule, rates, and N sources; Fe and plant growth regulator applications; turfgrass quality and color expectations; green speed expectations; and others.

Lower annual N fertility rates resulted in significantly lower: visual turfgrass quality and color; clipping yield; recovery from core cultivations; and shoot density. There also a non-significant trend that lower annual N fertility rates resulted in more *Rhizoctonia* brown patch coverage along with lower seedhead coverage.

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Acknowledgment

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Table 1. N, P_2O_5, K_2O, and Fe application schedule for the N fertility study on a *Poa annua*-creeping bentgrass putting green.

	Application dates for first 12 months of the study																		
	2006									2005									
	11 Jan.	1 Feb.	22 Feb.	15 Mar.	12 Apr.	13 Apr.	4 May	25 May	15 June	6 July	27 July	17 Aug.	7 Sept.	28 Sept.	19 Oct.	9 Nov.	30 Nov.	21 Dec.	
	Application dates for second 12 months of the study																		
	2007											2006							
Fertilizer component	10 Jan.	31 Jan.	21 Feb.	14 Mar.	4 Apr.	25 Apr.	3 May	24 May	12 June	5 July	26 July	16 Aug.	6 Sept.	27 Sept.	18 Oct.	8 Nov.	29 Nov.	20 Dec.	Annual total[z]
	lb/1000 ft²																		
N5.5	0.20	0.30	0.30	0.40	0.40	0.40	0.40	0.30	0.20	0.20	0.20	0.20	0.20	0.40	0.40	0.40	0.40	0.20	5.5
N4.2	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.20	4.2
N2.8	0.10	0.10	0.20	0.20	0.30	0.20	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.10	2.8
N1.5	–	–	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	–	1.5
	Applied to all plots																		
P_2O_5	–	–	0.25	0.25	0.25	0.25	–	–	–	–	–	–	0.25	0.25	0.25	0.25	–	–	2.0
K_2O	–	–	0.20	0.20	0.20	0.20	0.40	0.40	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.40	–	4.0
Fe	Ferrous sulfate ($FeSO_4$) applied by golf course superintendent once every 2 weeks at a rate of 2.0 oz/1000 ft².																		
PGR	Primo Maxx applied by golf course superintendent once every 2 weeks at 0.125 oz/1000 ft².																		

[z]Plots were irrigated with recycled water. The water supplies an annual N rate of approximately 0.5 lb/1000 ft² (including ammonia, organic, nitrate, and nitrite forms of N).

Note: There were three replications of each of four N fertility rates. Individual plot size = 6.0 x 11.0 ft.

Note: N sources were ammonium nitrate (20-0-0; 10.55 lb/gal) for December, January, and February; ammonium sulfate (8-0-0-9S; 10.2 lb/gal) for March and April; and low biuret urea (20-0-0; 9.35 lb/gal) from May through November. P source was ammonium polyphosphate (10-34-0; 11.7 lb/gal). K source was potassium sulfate ESP-K (1-0-8-2.5S; 9.7 lb/gal). Finish spray volume for each N fertility rate treatment application was 2.0 gal/1000 ft². All N fertility-rate treatments were applied with a CO_2 sprayer mounted on a cart.

Table 2. Summary of cultural management for the N fertility study on a *Poa annua*-creeping bentgrass putting green.

Mowing: Putting green nursery was mowed 5 to 6 times per week at a 0.140-inch height of cut. A walk-behind 22.0-inch wide Jacobsen greens mower was used, except on weekends when a triplex mower was used. Groomers were attached to walk-behind mowers.

Rolling: Putting green nursery was rolled 1 or 2 times per week.

Irrigation: Putting green nursery was irrigated for optimal putting green conditions. Syringing and hand watering was applied as needed. Leaching with 1.5 to 3.0 inch of water occurred the last Sunday of each summer month, or as needed. Note that the green was not watered with the irrigation system from March to mid-May 2006 due to construction on the golf course. During this time, water was transported by a water truck and the green was watered by hand using a hose.

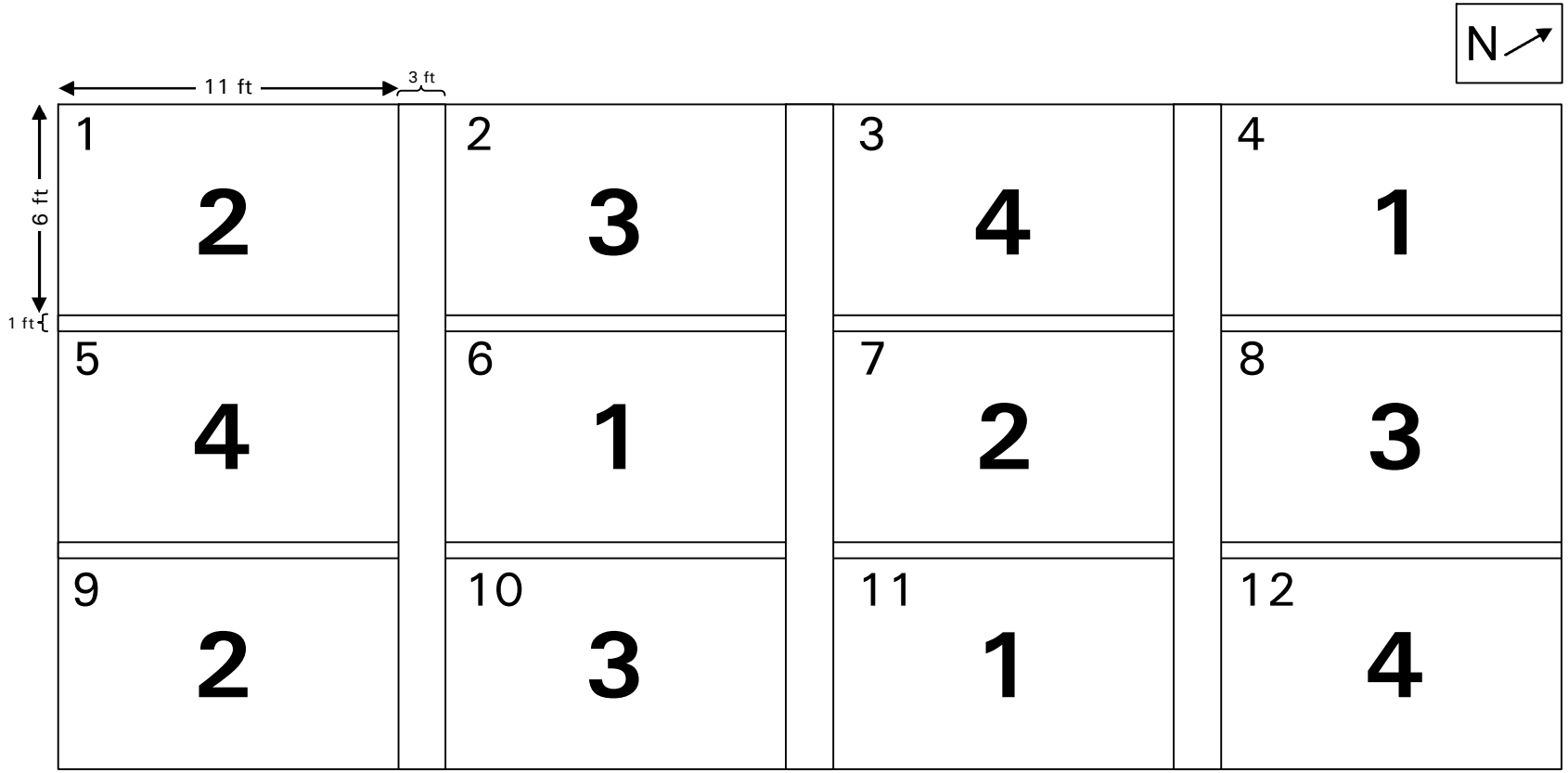
Core Cultivation: Core cultivations occurred on 22 Feb. and 16 May 2006 and 19 Mar. 2007 with 0.50-inch diameter hollow tines and cores were removed. Cultivations were followed with sufficient topdressing.

Verticutting: Verticutting was conducted as needed followed by light topdressing.

Light Topdressing: Light topdressing occurred 8 to 9 times per year.

Pesticide Applications: Insecticides and herbicides were applied as needed. Fungicides were applied to prevent moderate to severe disease activity.

Figure 1. Plot map for the N fertility study on a *Poa annua*-creeping bentgrass putting green at Industry Hills Golf Club at Pacific Palms Conference Resort, Industry, California.



Annual N fertility rate:
1 = 5.5 lb/1000 ft^2
2 = 4.2 lb/1000 ft^2
3 = 2.8 lb/1000 ft^2
4 = 1.5 lb/1000 ft^2

Figure 2. The effect of annual N fertility rate on visual turfgrass quality of a *Poa annua*-creeping bentgrass putting green from June 2005 to May 2007 (1 to 9 scale, with 1 = worst, 5 = minimally acceptable, and 9 = best putting green).

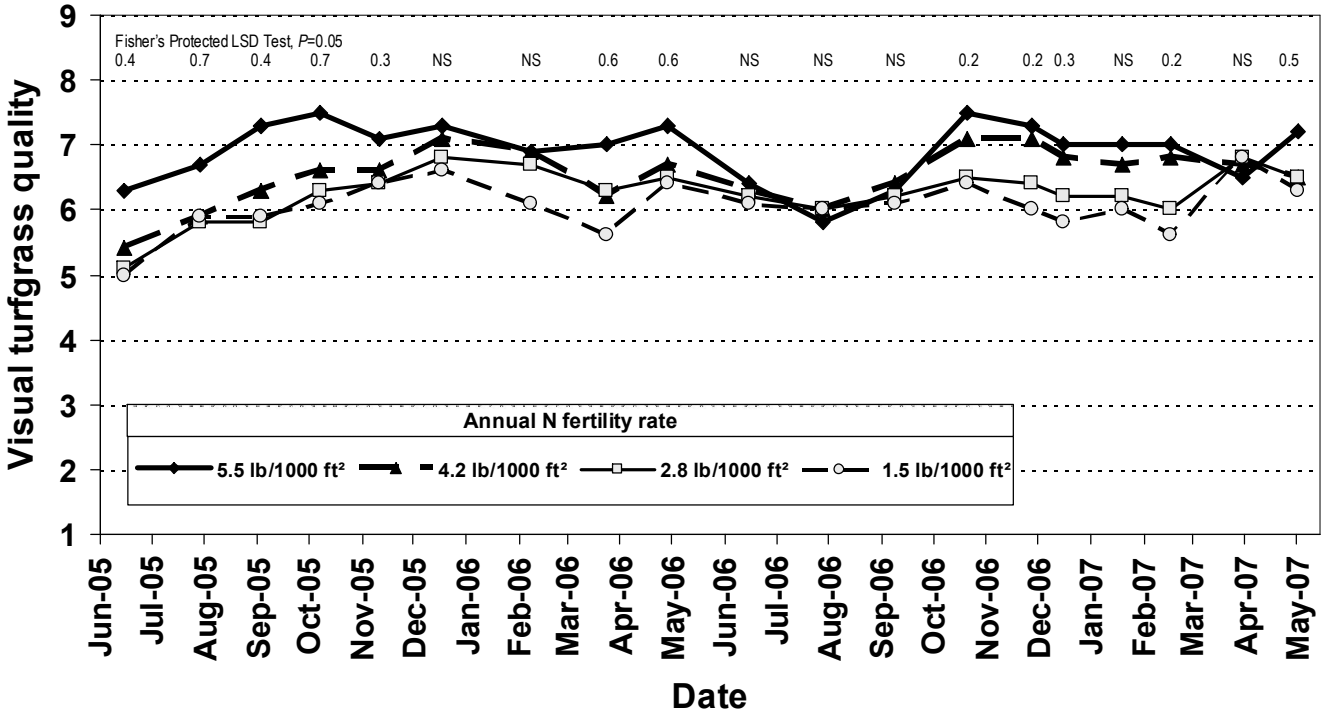


Figure 3. The effect of annual N fertility rate on visual turfgrass color of a *Poa annua*-creeping bentgrass putting green from June 2005 to May 2007 (1 to 9 scale, with 1 = brown, 5 = minimally acceptable, and 9 = darkest green putting green).

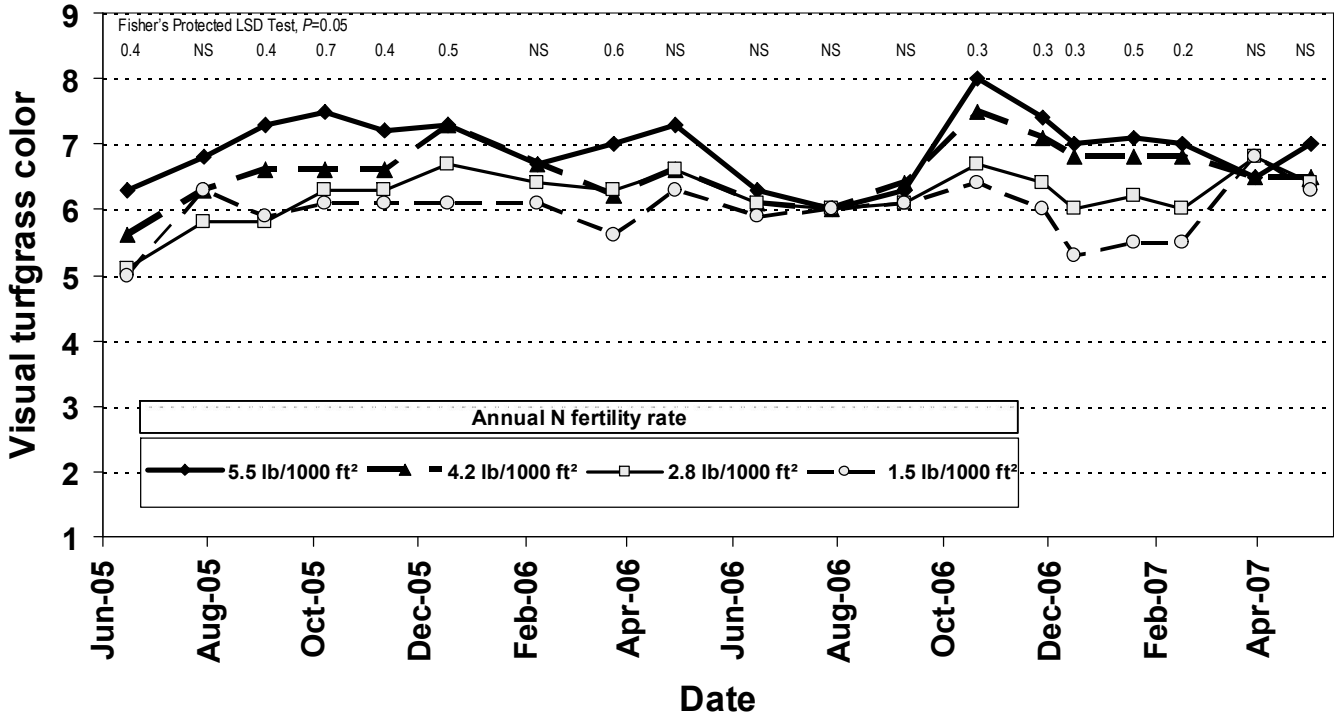
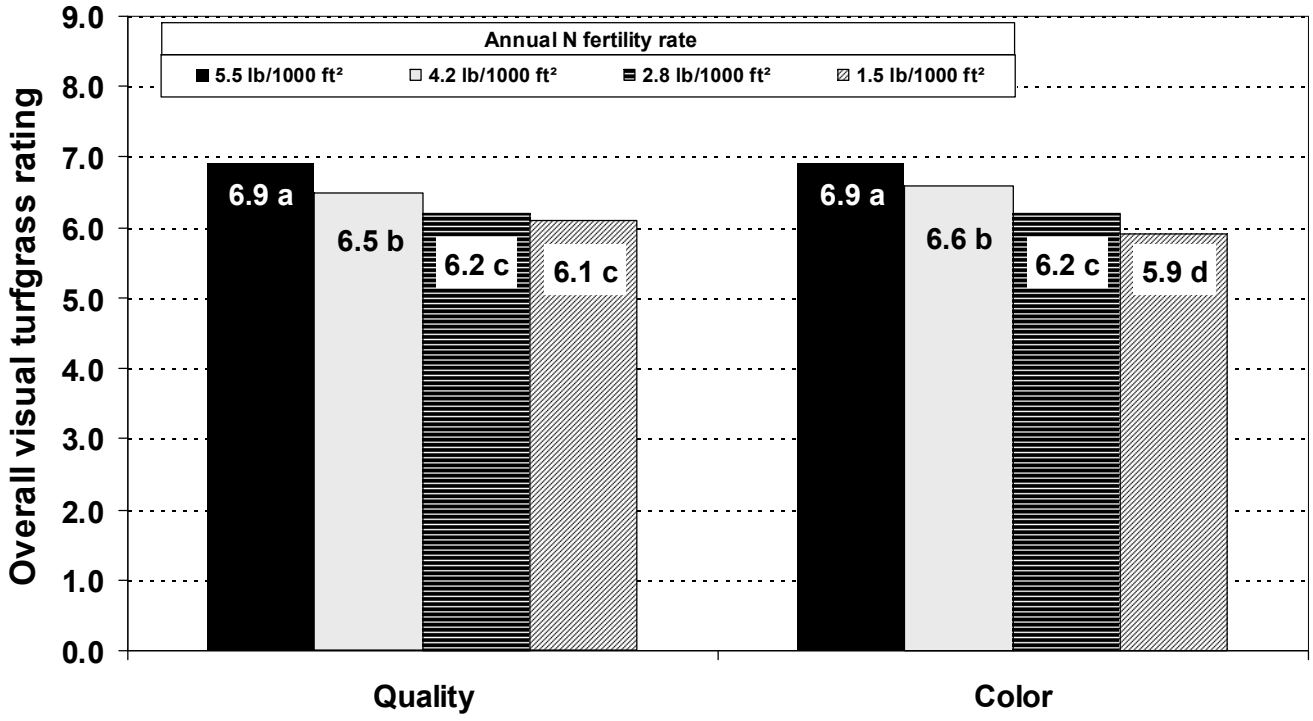


Figure 4. The effect of annual N fertility rate on overall visual turfgrass quality (1 to 9 scale, with 1 = worst, 5 = minimally acceptable, and 9 = best putting green) and color (1 to 9 scale, with 1 = brown, 5 = minimally acceptable, and 9 = darkest green putting green) of a *Poa annua*-creeping bentgrass putting green from June 2005 to May 2007.



Note: Means followed by the same letter are not significantly different, Fisher's Protected LSD Test, $P = 0.05$.

Table 3.1. The effect of annual N fertility rate on visual turfgrass quality of a *Poa annua*-creeping bentgrass putting green from June 2005 to June 2006 (1 to 9 scale, with 1 = worst, 5 = minimally acceptable, and 9 = best putting green).

Annual N fertility rate	29 June 2005	12 Aug. 2005	16 Sept. 2005	21 Oct. 2005	25 Nov. 2005	30 Dec. 2005	21 Feb. 2006[y]	7 Apr. 2006[y]	12 May 2006	29 June 2006
5.5 lb/1000 ft^2	6.3	6.7	7.3	7.5	7.1	7.3	6.9	7.0	7.3	6.4
4.2 lb/1000 ft^2	5.4	5.9	6.3	6.6	6.6	7.1	6.9	6.2	6.7	6.3
2.8 lb/1000 ft^2	5.1	5.8	5.8	6.3	6.4	6.8	6.7	6.3	6.5	6.2
1.5 lb/1000 ft^2	5.0	5.9	5.9	6.1	6.4	6.6	6.1	5.6	6.4	6.1
LSD, $P=0.05$[z]	0.4	0.7	0.4	0.7	0.3	NS	NS	0.6	0.6	NS
P-value										
N rate (N)	0.0013	0.0471	0.0008	0.0204	0.0110	0.0762	0.0909	0.0108	0.0314	0.4071

[z]Mean separation within columns by Fisher's protected LSD test, $P=0.05$.

[y]The presence of seedheads slightly lowered these ratings; there was no apparent N fertility rate treatment effect on seedhead coverage.

Table 3.2. The effect of annual N fertility rate on visual turfgrass quality of a *Poa annua*-creeping bentgrass putting green from August 2006 to May 2007 (1 to 9 scale, with 1 = worst, 5 = minimally acceptable, and 9 = best putting green).

Annual N fertility rate	11 Aug. 2006	22 Sept. 2006	3 Nov. 2006	11 Dec. 2006	29 Dec. 2006	2 Feb. 2007	2 Mar. 2007	13 Apr. 2007	16 May 2007	Overall
5.5 lb/1000 ft^2	5.8	6.3	7.5	7.3	7.0	7.0	7.0	6.5	7.2	6.9
4.2 lb/1000 ft^2	6.0	6.4	7.1	7.1	6.8	6.7	6.8	6.7	6.5	6.5
2.8 lb/1000 ft^2	6.0	6.2	6.5	6.4	6.2	6.2	6.0	6.8	6.5	6.2
1.5 lb/1000 ft^2	6.0	6.1	6.4	6.0	5.8	6.0	5.6	6.8	6.3	6.1
LSD, $P=0.05$[z]	NS	NS	0.2	0.2	0.3	NS	0.2	NS	0.5	0.2
P-value										
N rate (N)	0.5304	0.7919	0.0002	0.0003	0.0006	0.0609	<0.0001	0.3414	0.0256	0.0004
Date (D)										<0.0001
N x D										<0.0001

[z]Mean separation within columns by Fisher's protected LSD test, $P=0.05$.

[y]The presence of seedheads slightly lowered these ratings; there was no apparent N fertility rate treatment effect on seedhead coverage.

Table 4.1. The effect of annual N fertility rate on visual turfgrass color of a *Poa annua*-creeping bentgrass putting green from June 2005 to June 2006 (1 to 9 scale, with 1 = brown, 5 = minimally acceptable, and 9 = darkest green putting green).

Annual N fertility rate	29 June 2005	12 Aug. 2005	16 Sept. 2005	21 Oct. 2005	25 Nov 2005	30 Dec. 2005	21 Feb. 2006[y]	7 Apr. 2006[y]	12 May 2006	29 June 2006
5.5 lb/1000 ft^2	6.3	6.8	7.3	7.5	7.2	7.3	6.7	7.0	7.3	6.3
4.2 lb/1000 ft^2	5.6	6.3	6.6	6.6	6.6	7.3	6.7	6.2	6.6	6.1
2.8 lb/1000 ft^2	5.1	5.8	5.8	6.3	6.3	6.7	6.4	6.3	6.6	6.1
1.5 lb/1000 ft^2	5.0	6.3	5.9	6.1	6.1	6.1	6.1	5.6	6.3	5.9
LSD, $P=0.05$[z]	0.4	NS	0.4	0.7	0.4	0.5	NS	0.6	NS	NS
P-value										
N rate (N)	0.0025	0.1947	0.0007	0.0204	0.0080	0.0073	0.1576	0.0108	0.0708	0.5772

[z]Mean separation within columns by Fisher's protected LSD test, $P=0.05$.

[y]The presence of seedheads slightly lowered these ratings; there was no apparent N fertility rate treatment effect on seedhead coverage.

Table 4.2. The effect of annual N fertility rate on visual turfgrass color of a *Poa annua*-creeping bentgrass putting green from August 2006 to May 2007 (1 to 9 scale, with 1 = brown, 5 = minimally acceptable, and 9 = darkest green putting green).

Annual N fertility rate	11 Aug. 2006	22 Sept. 2006	3 Nov. 2006	11 Dec. 2006	29 Dec. 2006	2 Feb. 2007	2 Mar. 2007	13 Apr. 2007	16 May 2007	Overall
5.5 lb/1000 ft^2	6.0	6.3	8.0	7.4	7.0	7.1	7.0	6.5	7.0	6.9
4.2 lb/1000 ft^2	6.0	6.4	7.5	7.1	6.8	6.8	6.8	6.5	6.5	6.6
2.8 lb/1000 ft^2	6.0	6.1	6.7	6.4	6.0	6.2	6.0	6.8	6.4	6.2
1.5 lb/1000 ft^2	6.0	6.1	6.4	6.0	5.3	5.5	5.5	6.8	6.3	5.9
LSD, $P=0.05$[z]	NS	NS	0.3	0.3	0.3	0.5	0.2	NS	NS	0.2
P-value										
N rate (N)	.	0.3532	<0.0001	0.0005	0.0001	0.0020	<0.0001	0.2468	0.1146	0.0002
Date (D)										<0.0001
N x D										<0.0001

[z]Mean separation within columns by Fisher's protected LSD test, $P=0.05$.

Figure 5. The effect of annual N fertility rate on percent coverage of *rhizoctonia* brown patch of a *Poa annua*-creeping bentgrass putting green on 30 Dec. 2005.

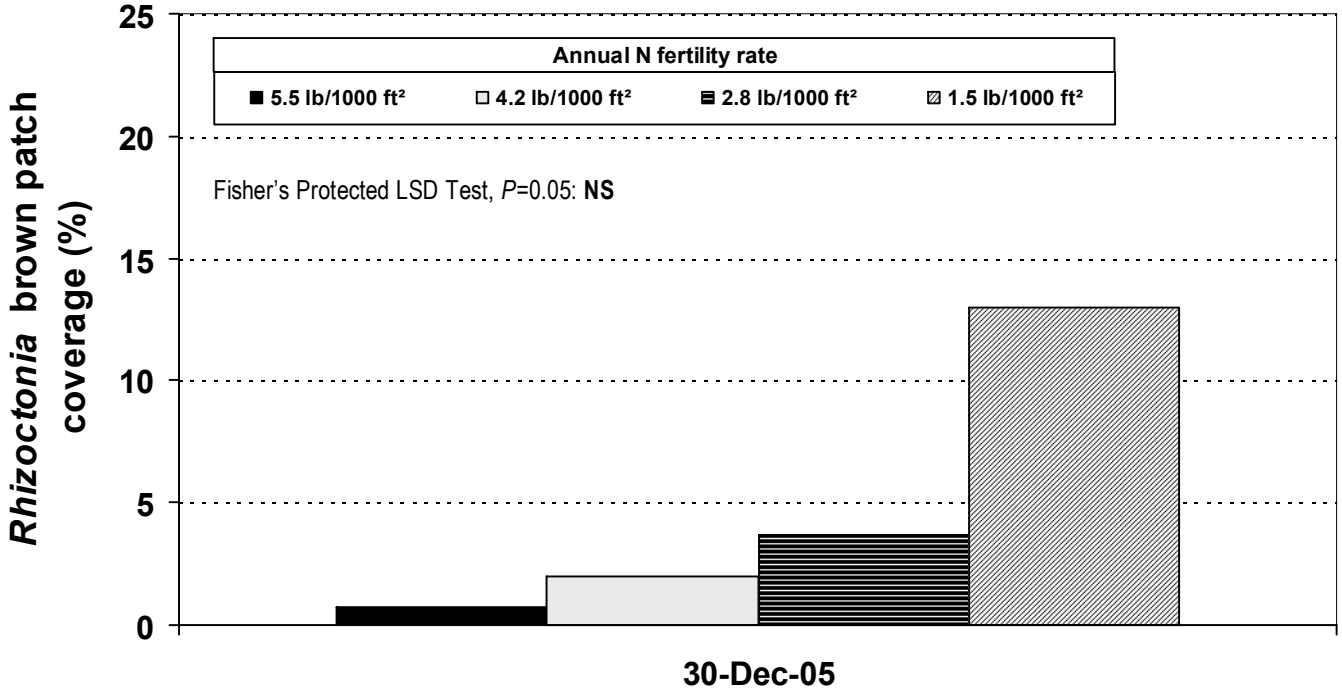
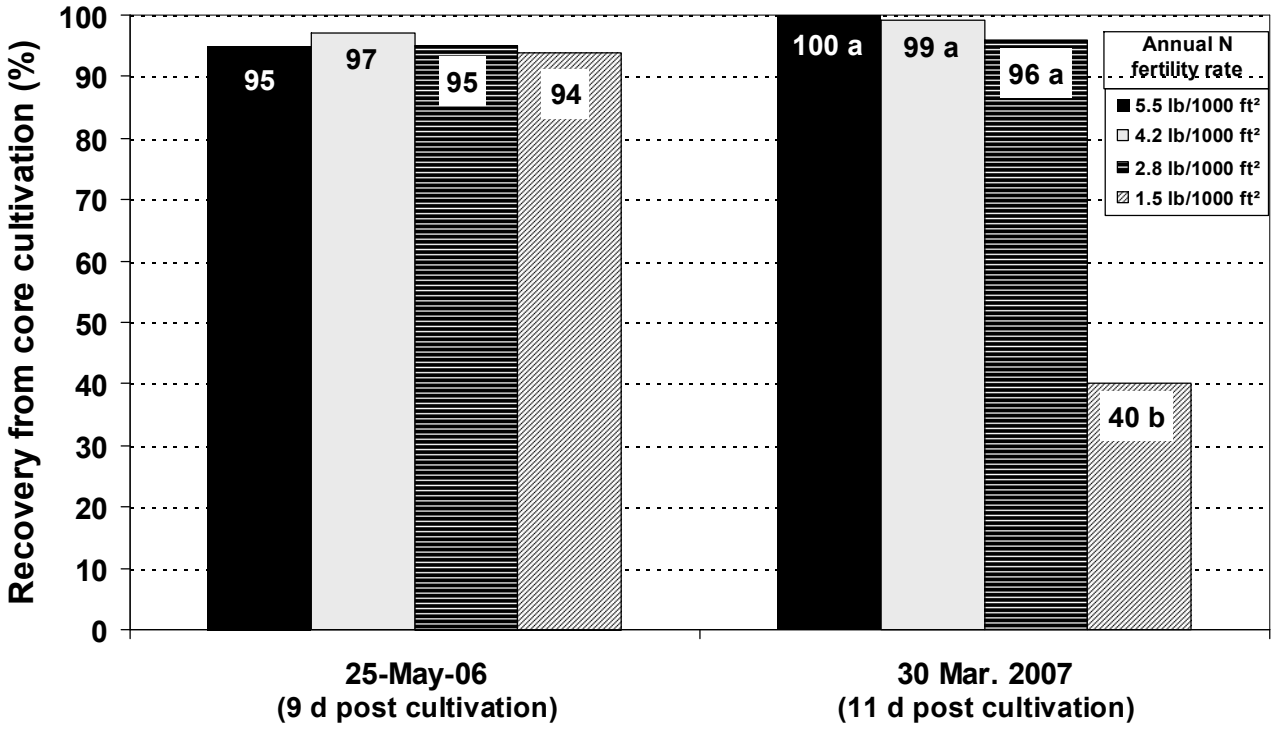


Table 5. The effect of annual N fertility rate on percent coverage of *rhizoctonia* brown patch of a *Poa annua*-creeping bentgrass putting green on 30 Dec. 2005.

Annual N fertility rate	30 Dec. 2005
5.5 lb/1000 ft^2	0.7
4.2 lb/1000 ft^2	2.0
2.8 lb/1000 ft^2	3.7
1.5 lb/1000 ft^2	13.0
LSD, $P=0.05$[z]	NS
P-value	0.2881

[z]Mean separation within columns by Fisher's protected LSD test, $P=0.05$.

Figure 6. The effect of annual N fertility rate on percent recovery from core cultivation[z] of a *Poa annua*-creeping bentgrass putting green.



[z]Core cultivations conducted on 16 May 2006 and 19 Mar. 2007 with 0.5-inch hollow tines and cores removed.
Note: Means followed by the same letter are not significantly different, Fisher's Protected LSD Test, $P = 0.05$.

Table 6. The effect of annual N fertility rate on percent recovery from core cultivation[z] of a *Poa annua*-creeping bentgrass putting green.

Annual N fertility rate	25 May 2006 (9 d post cultivation)	30 Mar. 2007 (11 d post cultivation)
5.5 lb/1000 ft^2	95	100 a
4.2 lb/1000 ft^2	97	99 a
2.8 lb/1000 ft^2	95	96 a
1.5 lb/1000 ft^2	94	40 b
LSD, $P=0.05$[y]	NS	6
P-value	0.1952	<0.0001

[z]Core cultivations conducted on 16 May 2006 and 19 Mar. 2007 with 0.5-inch hollow tines and cores removed.
[y]Mean separation within columns by Fisher's protected LSD test, $P=0.05$.

Figure 7. The effect of annual N fertility rate on percent *Poa annua* seedhead coverage.

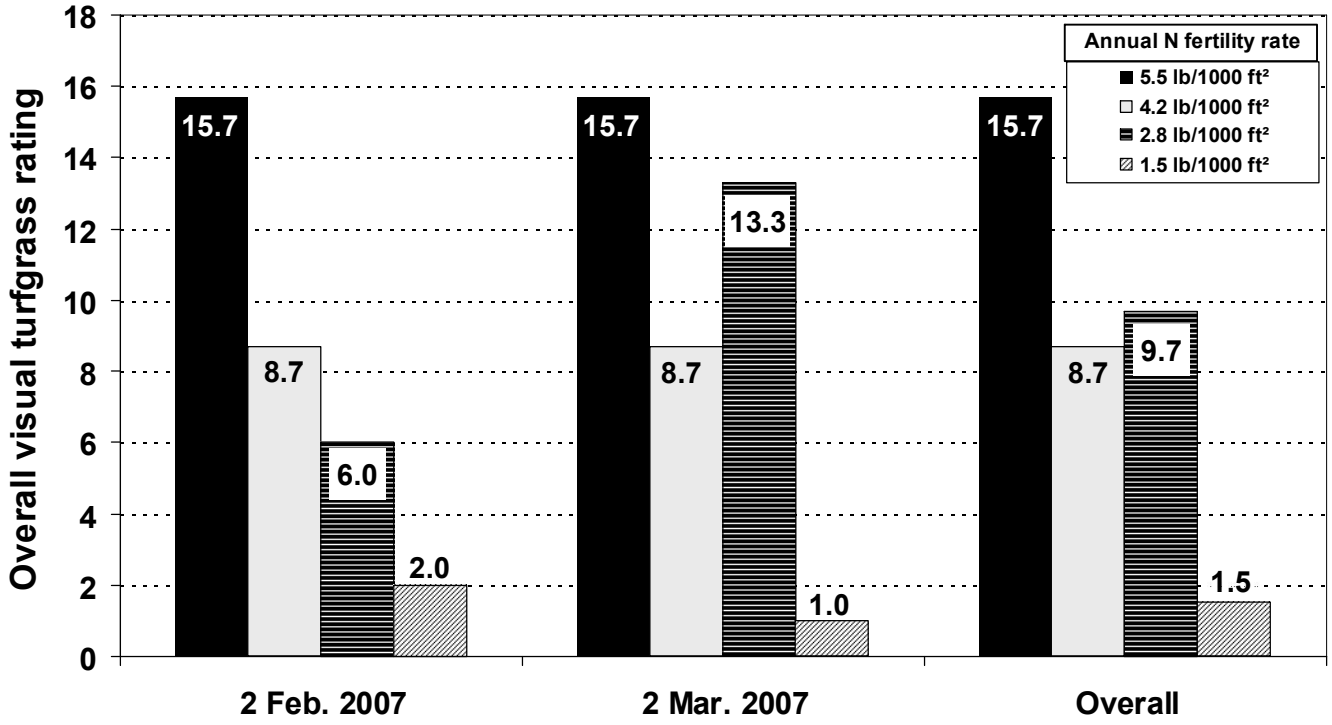


Table 7. The effect of annual N fertility rate on percent *Poa annua* seedhead coverage.

Annual N fertility rate	2 Feb. 2007	2 Mar. 2007	Overall
5.5 lb/1000 ft^2	15.7	15.7	15.7
4.2 lb/1000 ft^2	8.7	8.7	8.7
2.8 lb/1000 ft^2	6.0	13.3	9.7
1.5 lb/1000 ft^2	2.0	1.0	1.5
LSD, $P=0.05$[z]	NS	NS	NS
P-value			
N rate (N)	0.4257	0.4541	0.4832
Date (D)			0.1256
N x D			0.0654

[z]Mean separation within columns by Fisher's protected LSD test, $P=0.05$.

Figure 8. The effect of annual N fertility rate on clipping yield of a *Poa annua*-creeping bentgrass putting green from July 2005 to January 2006 and August 2006 to April 2007.

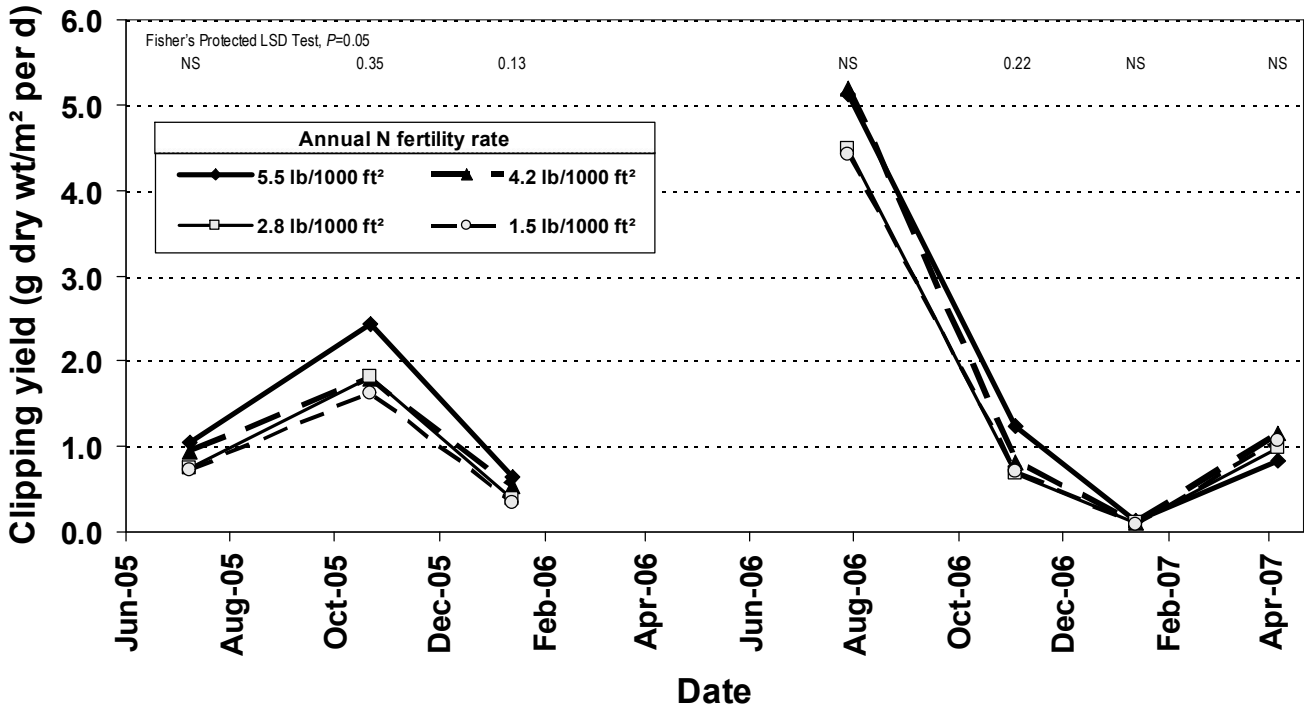
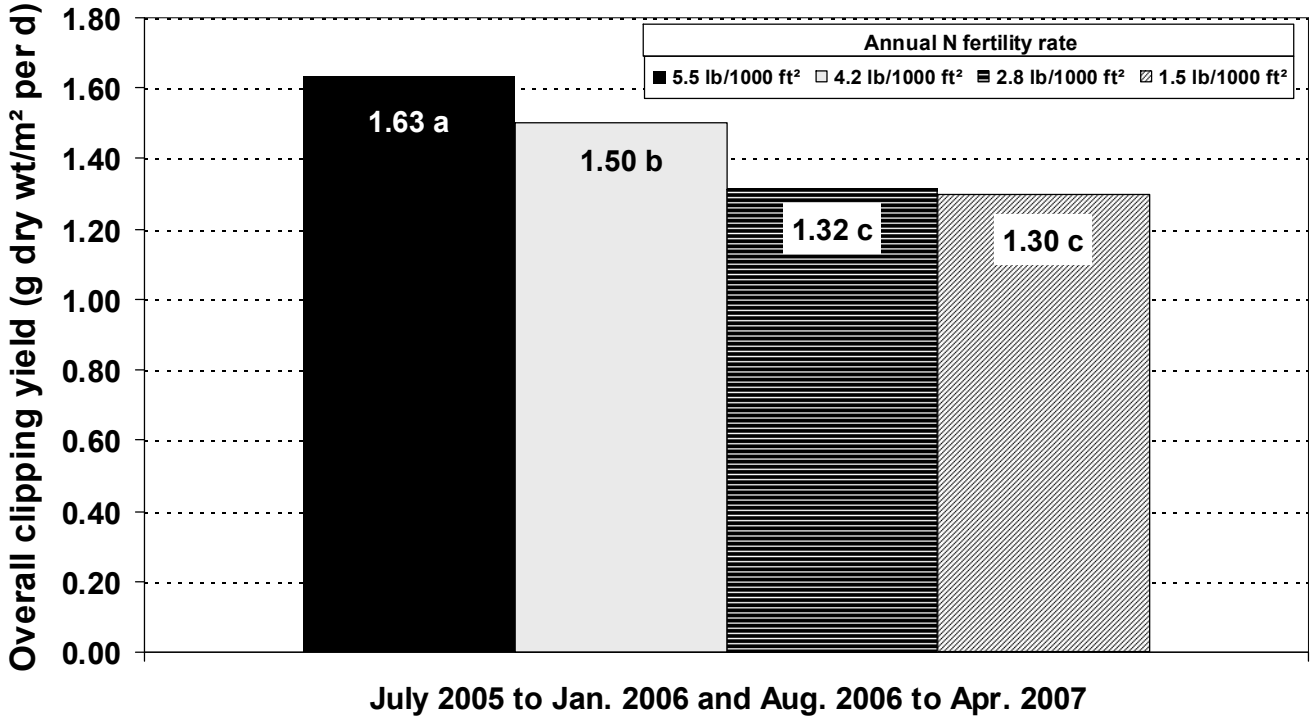


Figure 9. The effect of annual N fertility rate on overall clipping yield of a *Poa annua*-creeping bentgrass putting green from July 2005 to January 2006 and August 2006 to April 2007.



Note: Means followed by the same letter are not significantly different, Fisher's Protected LSD Test, $P = 0.05$.

Figure 10. The effect of annual N fertility rate on total N concentration in clipping tissue from a *Poa annua*-creeping bentgrass putting green from July 2005 to January 2006 and August 2006 to April 2007.

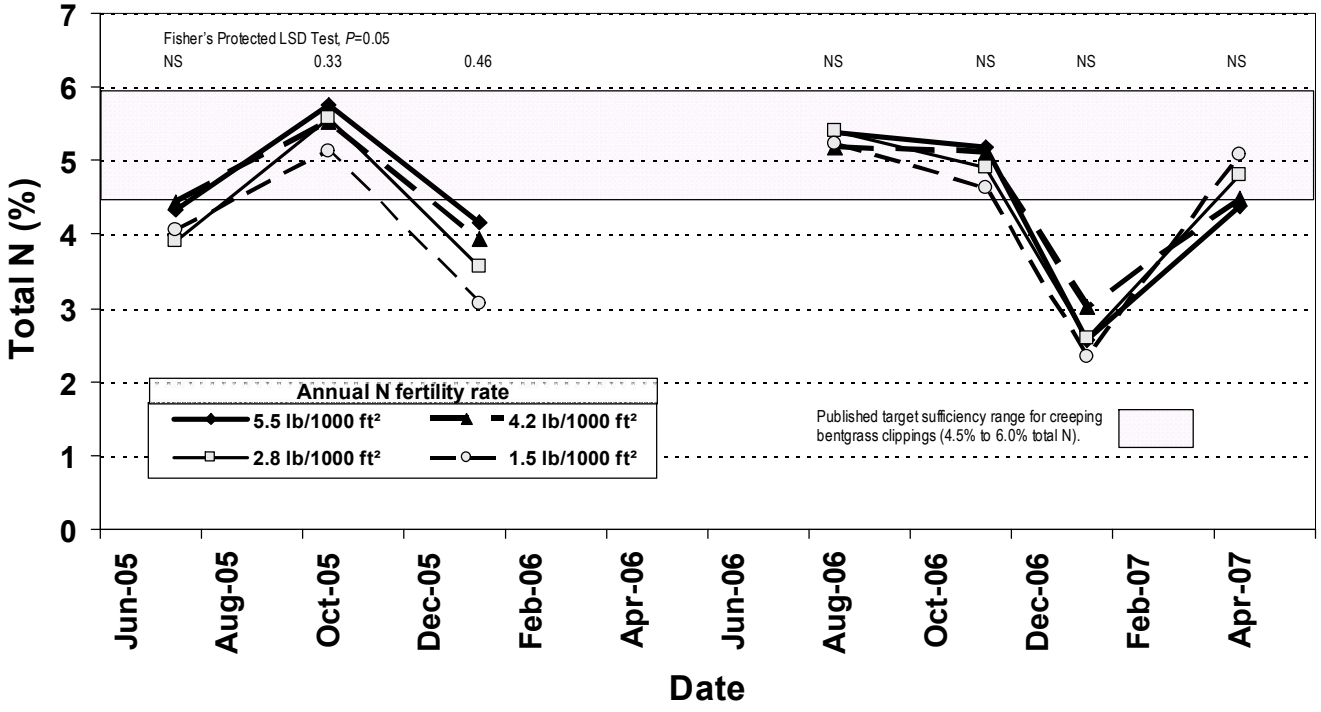


Figure 11. The effect of annual N fertility rate on total P concentration in clipping tissue from a *Poa annua*-creeping bentgrass putting green from July 2005 to January 2006 and August 2006 to April 2007.

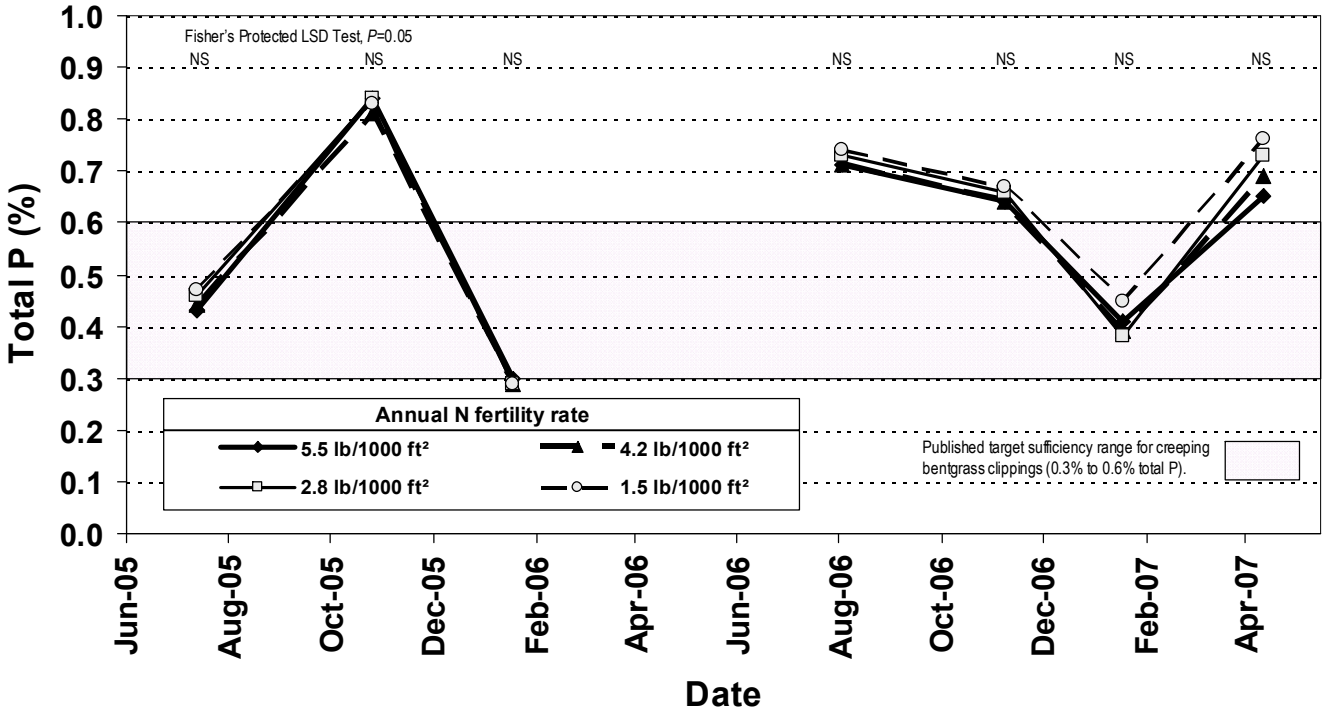


Figure 12. The effect of annual N fertility rate on total K concentration in clipping tissue from a *Poa annua*-creeping bentgrass putting green from July 2005 to January 2006 and August 2006 to April 2007.

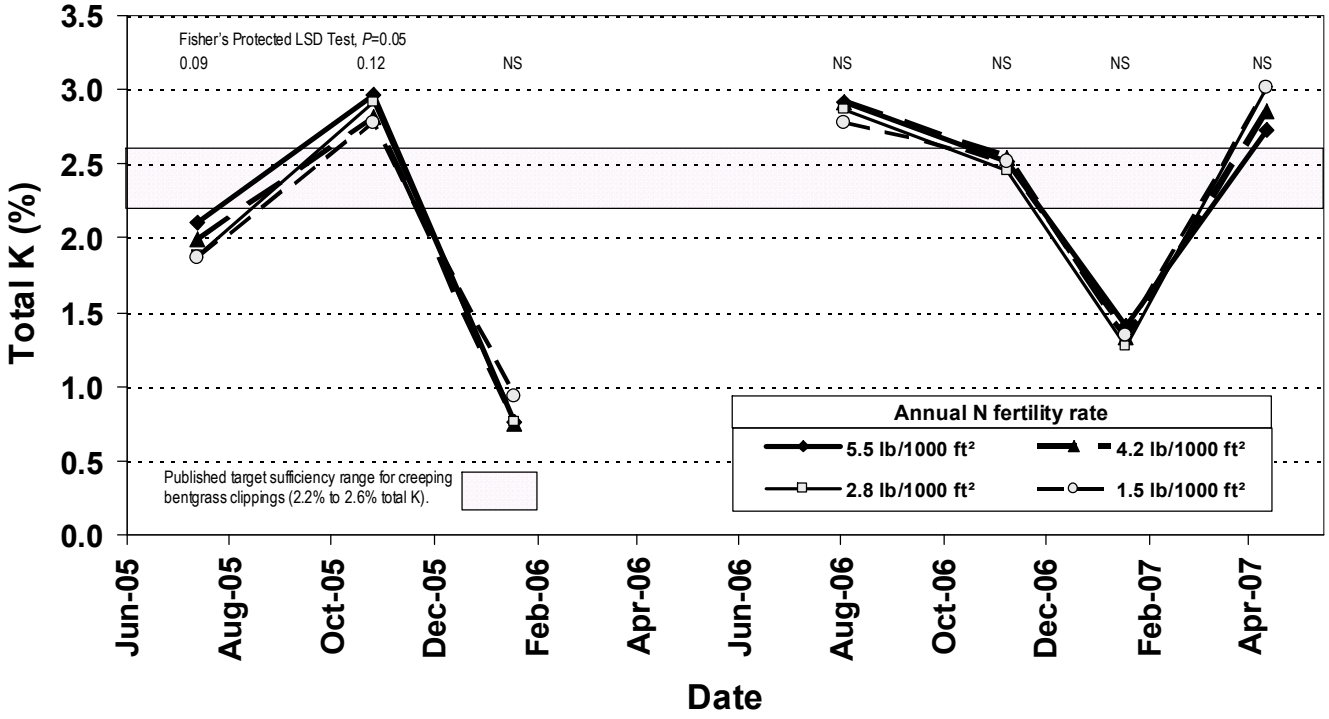


Table 8.1. The effect of annual N fertility rate on clipping yield, total N, P, and K concentrations in clipping tissue, and N, P, and K uptake of a *Poa annua*-creeping bentgrass putting green from July 2005 to August 2006.

		Nitrogen		Phosphorus		Potassium	
Annual N fertility rate	Yield	Total Kjeldhal N[y]	N uptake[x]	Total P[y]	P uptake[x]	Total K[y]	K uptake[x]
	g·m^{-2} per d	--------- % ---------	*g·m^{-2} per d*	-------- % --------	*g·m^{-2} per d*	-------- % --------	*g·m^{-2} per d*
13 July 2005							
5.5 lb/1000 ft^2	1.04	4.34	0.04	0.43	0.004	2.10	0.02
4.2 lb/1000 ft^2	0.93	4.44	0.04	0.44	0.004	1.99	0.02
2.8 lb/1000 ft^2	0.74	3.91	0.03	0.46	0.003	1.88	0.01
1.5 lb/1000 ft^2	0.73	4.07	0.03	0.47	0.003	1.87	0.01
LSD, $P=0.05$[z]	NS	NS	NS	NS	NS	0.09	NS
P-value	0.1580	0.0902	0.0676	0.2136	0.3391	0.0044	0.0655
26 Oct. 2005							
5.5 lb/1000 ft^2	2.44	5.76	0.14	0.84	0.020	2.97	0.07
4.2 lb/1000 ft^2	1.79	5.54	0.10	0.81	0.015	2.81	0.05
2.8 lb/1000 ft^2	1.82	5.58	0.10	0.84	0.015	2.91	0.05
1.5 lb/1000 ft^2	1.63	5.13	0.08	0.83	0.014	2.78	0.05
LSD, $P=0.05$[z]	0.35	0.33	0.02	NS	0.003	0.12	0.01
P-value	0.0065	0.0227	0.0033	0.5140	0.0078	0.0269	0.0038
18 Jan. 2006							
5.5 lb/1000 ft^2	0.63	4.16	0.03	0.30	0.0019	0.76	0.005
4.2 lb/1000 ft^2	0.53	3.93	0.02	0.29	0.0015	0.75	0.004
2.8 lb/1000 ft^2	0.38	3.57	0.01	0.29	0.0011	0.76	0.003
1.5 lb/1000 ft^2	0.35	3.06	0.01	0.29	0.0010	0.93	0.003
LSD, $P=0.05$[z]	0.13	0.46	0.01	NS	0.0003	NS	NS
P-value	0.0067	0.0098	0.0058	0.9255	0.0041	0.2193	0.0589
2 Aug. 2006							
5.5 lb/1000 ft^2	5.13	5.38	0.28	0.71	0.04	2.92	0.15
4.2 lb/1000 ft^2	5.19	5.19	0.27	0.71	0.04	2.91	0.15
2.8 lb/1000 ft^2	4.49	5.41	0.24	0.73	0.03	2.87	0.13
1.5 lb/1000 ft^2	4.43	5.23	0.24	0.74	0.03	2.78	0.13
LSD, $P=0.05$[z]	NS	NS	NS	NS	NS	NS	NS
P-value	0.3094	0.4804	0.4739	0.2688	0.4588	0.4062	0.1778

[z] Mean separation within columns by Fisher's protected LSD test, $P=0.05$.

[y] Reported target ranges for total N, P, and K concentrations in creeping bentgrass clipping tissue are 4.5% to 6.0%, 0.3% to 0.6%, and 2.2% to 2.6%, respectively.

[x] Calculated as yield mass x concentration of total N, P, or K.

Table 8.2. The effect of annual N fertility rate on clipping yield, total N, P, and K concentrations in clipping tissue, and N, P, and K uptake of a *Poa annua*-creeping bentgrass putting green from November 2006 to April 2007.

		Nitrogen		Phosphorus		Potassium	
Annual N fertility rate	Yield	Total Kjeldhal N[y]	N uptake[x]	Total P[y]	P uptake[x]	Total K[y]	K uptake[x]
	g·m^{-2} per d	--------- % ---------	*g·m^{-2} per d*	-------- % --------	*g·m^{-2} per d*	-------- % --------	*g·m^{-2} per d*
8 Nov. 2006							
5.5 lb/1000 ft^2	1.23	5.19	0.06	0.64	0.008	2.52	0.03
4.2 lb/1000 ft^2	0.81	5.11	0.04	0.64	0.005	2.54	0.02
2.8 lb/1000 ft^2	0.69	4.90	0.03	0.66	0.005	2.45	0.02
1.5 lb/1000 ft^2	0.71	4.64	0.03	0.67	0.005	2.52	0.02
LSD, $P=0.05$[z]	0.22	NS	0.01	NS	0.001	NS	0.01
P-value	0.0045	0.3442	0.0018	0.7929	0.0044	0.9087	0.0027
17 Jan. 2007							
5.5 lb/1000 ft^2	0.12	2.57	0.003	0.41	0.0005	1.41	0.002
4.2 lb/1000 ft^2	0.11	3.01	0.003	0.39	0.0004	1.33	0.001
2.8 lb/1000 ft^2	0.11	2.60	0.003	0.38	0.0004	1.27	0.001
1.5 lb/1000 ft^2	0.08	2.34	0.002	0.45	0.0004	1.34	0.001
LSD, $P=0.05$[z]	NS	NS	NS	NS	NS	NS	NS
P-value	0.7718	0.5727	0.7253	0.1292	0.8192	0.3356	0.5895
11 Apr. 2007							
5.5 lb/1000 ft^2	0.84	4.39	0.04	0.65	0.01	2.73	0.02
4.2 lb/1000 ft^2	1.16	4.49	0.05	0.69	0.01	2.85	0.03
2.8 lb/1000 ft^2	0.98	4.80	0.05	0.73	0.01	3.01	0.03
1.5 lb/1000 ft^2	1.07	5.09	0.05	0.76	0.01	3.01	0.03
LSD, $P=0.05$[z]	NS	NS	NS	NS	NS	NS	NS
P-value	0.4305	0.2140	0.4926	0.0794	0.4061	0.2056	0.4721

[z] Mean separation within columns by Fisher's protected LSD test, $P=0.05$.

[y] Reported target ranges for total N, P, and K concentrations in creeping bentgrass clipping tissue are 4.5% to 6.0%, 0.3% to 0.6%, and 2.2% to 2.6%, respectively.

[x] Calculated as yield mass x concentration of total N, P, or K.

Table 9a. Analyses of soil salinity/alkalinity/toxicity, fertility and textural characteristics from samples taken at the 0- to 4-inch depth rootzone on 8 Apr. 2005.

	Sample date
	8 Apr. 2005
Soil salinity/alkalinity/toxicity[z]	
pH	6.8
Soluble Ca (ppm)	136
Soluble K (ppm)	1611
Soluble Mg (ppm)	29
Soluble Na (ppm)	115
SAR	2
ESP (%)	2
CO_3 (ppm)	< 3
HCO_3 (ppm)	177
CEC (meq/100 g)	< 2.0
Soil fertility[z]	
Extractable Fe (ppm)	14.9
Olsen-P (ppm)	7.2
Exchangeable K (ppm)	64
Exchangeable Ca (ppm)	591
Exchangeable Mg (ppm)	69
Exchangeable Na (ppm)	52
TKN (%)	0.047
Soil textural characteristics[z]	
OM (%)	0.80
Sand (%)	93
Silt (%)	5
Clay (%)	2

[z]Analyses conducted according to relevant DANR analytical methodologies.

Table 9b. Analyses of soil fertility and organic matter[z] from samples taken at the 0- to 4-inch depth rootzone on 3 May 2006 and 25 May 2007.

Annual N fertility rate	Olsen-P (ppm)		Exchangeable K (ppm)		Exchangeable Ca (ppm)		Exchangeable Mg (ppm)		Exchangeable Na (ppm)		TKN (%)		OM (%)	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
5.5 lb/1000 ft^2	13.2	11.4	32	44	519	597	68	74	44	61	0.035	0.060	0.71	1.06
4.2 lb/1000 ft^2	10.0	11.4	29	39	513	609	64	72	36	50	0.033	0.046	0.61	0.92
2.8 lb/1000 ft^2	13.2	16.1	34	50	557	621	70	79	43	59	0.040	0.058	0.71	1.12
1.5 lb/1000 ft^2	11.2	17.2	38	56	551	595	69	75	37	60	0.033	0.058	0.74	1.07

[z]Analyses conducted according to relevant DANR analytical methodologies.

Table 10. The effect of annual N fertility rate on shoot density and root mass density of a *Poa annua*-creeping bentgrass putting green.

Annual N fertility rate	Shoot density[z]	Root mass density[z]	
		Root-depth zone (inch)	
		0 to 3	3 to 6
	shoots/cm^2	mg/cm^3	
5.5 lb/1000 ft^2	34.4 b	8.4 a	0.1 a
4.2 lb/1000 ft^2	45.5 a	4.0 a	0.1 a
2.8 lb/1000 ft^2	30.9 b	7.7 a	0.2 a
1.5 lb/1000 ft^2	21.7 c	7.4 a	0.2 a
LSD, $P=0.05$[y]	7.8	NS	NS
ANOVA effect (P)			
Treatment	0.0018	0.6418	0.6252

[z] Determination from cores which were taken on May 25, 2007.

[y] Mean separation within columns by Fisher's protected LSD test, $P=0.05$.