This is to certify that the

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EFFECTS OF ROLLING AND FERTILITY ON DIFFERENT

ROOT ZONES

presented by

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EFFECTS OF ROLLING AND FERTILITY ON DIFFERENT ROOT ZONES

By

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ABSTRACT

EFFECTS OF ROLLING AND FERTILITY ON DIFFERENT ROOT ZONES

By

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Research greens constructed with different root zones: an 80:20 (sand: peat v/v) mixture constructed to USGA recommendations; an 80:10:10 (sand: soil: peat v/v) mixture 0.3m deep built with subsurface tile drainage; and an undisturbed sandy clay loam native soil green were established in 1993 with the specific purpose to compare among different soils managed under similar management regimes. Each green was split for lightweight green rolling that was split for fertility treatments. Rolling treatments consisted of rolled 3x/week and not rolled. Fertility treatments consisted of two nitrogen rates (146 and 293 kg ha^{-1} $year^{-1}$) and three potassium rates (0, 195, and 390 K_2O kg ha^{-1} $year^{-1}$). The study took place 3-7 years after the greens were seeded with 'Penncross' creeping bentgrass (*Agrostis palustris* Huds.). All root zones were on a frequent sand topdressing program.

The native soil root zone had higher levels of total-N, and available P, K, Ca, and Mg, than the soil-less 80:20 root zone. However, few significant differences resulted between the 80:20 root zone and the 80:10:10 root zone.

The native soil root zone resulted in significantly more plant tissue K than the 80:20 root zone from 1997-1999. In 2000 no significant differences resulted from any of

the root zones for any of the plant tissue nutrients. At that time the mean sand topdressing layer (STL) was 43mm deep and approximately 75% of the roots were located in the STL regardless of root zone. Additionally, there was an inverse relationship between the amount of fines in the root zone and dollar spot (*Sclerotinia homoeocarpa*) severity.

Lightweight green rolling three times per week resulted in few statistically significant differences in soil physical properties. Lightweight rolling significantly increased ball roll distance and root mass in the STL, and reduced dollar spot, bird beak intrusions, broadleaf weeds, and localized dry spot.

Nitrogen rate consistently resulted in significant differences in dollar spot counts, but the amount of time passing after nitrogen application appeared to be a factor. The higher rate of N resulted in fewer dollar spot counts when N fertility averaged 14 days after application while the lower N rate had less dollar spot when N fertility averaged 32 days after application. The lower rate of N had significantly greater ball roll distance than the higher N rate and the differences increased between the two N rates with differences of 8cm in 1998, 10 cm in 1999, and 19 cm in 2000.

The higher N rate decreased soil test K and P from 1998-2000. Clipping yields and plant tissue analyses indicate that the decrease in soil K may be the result of increased growth and nutrient uptake related to the higher N rate. Results of plant tissue P were not consistent.

Potassium had no effect on clipping weights but did result in increased root growth one year in the STL. Potassium had no effect on ball roll distance, dollar spot, color, quality, or localized dry spot.

To my father, Henry Anthony Nikolai, for his encouragement, support, and love.

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KEY TO SYMBOLS OR ABBREVIATIONS

OMC, organic matter content; STL, sand topdressing layer; BRD, ball roll distance.

CHAPTER ONE

RESPONSE OF THREE PUTTING GREEN ROOT ZONES TO ROLLING

ABSTRACT

Research greens constructed with three root zones: an 80:20 (sand: peat v/v) mixture constructed to USGA recommendations; an 80:10:10 (sand: soil: peat v/v) mixture built with subsurface tile drainage; and an undisturbed sandy clay loam native soil green were evaluated for soil physical properties for a period of 3-7 years after seeding with 'Penncross' creeping bentgrass (*Agrostis palustris* Huds.).

Lightweight green rolling three times per week resulted in no significant differences in bulk density, capillary porosity, or saturated hydraulic conductivity. Significant differences included reduced air-filled porosity on the last three sampling dates and reduced total porosity on three of seven sampling dates. It is noteworthy that while there were no increases in bulk density associated with rolling, all plots were on a light, frequent sand topdressing program. Had greens not been on a sand topdressing program increases in bulk density may have resulted.

Organic matter content (OMC) in the root zones was measured four straight years with samples obtained in October of each year. Data from 1999 was determined to be erroneous and were discarded. No significant differences in OMC resulted in the sand topdressing layer (STL) among the root zones. One of three years OMC was significantly greater for the native soil root zone in the 0-7.6cm and 7.6-15.2cm depths below the STL. The OMC also significantly increased in the STL in all root zones with time.

Total-N content was greater in the native root zone than the 80:20 root zone with no significant differences occurring between the 80:20 and 80:10:10 root zones. Nitrate-N decreased with depth in the 80:20 root zone. There were no differences between the 80:10:10 and the 80:20 root zone in NO_3-N. On one date the 80:10:10 did have significantly greater retention of NH_4-N then the 80:20 root zone.

The 80:20 root zone had significantly higher saturated conductivity rates than the 80:10:10 root zone on all but one date and it was consistently higher than the native root zone on all dates. There were no significant differences between the 80:10:10 and the native root zone during the last five sampling dates.

No significant differences resulted between the 80:10:10 and the native root zones in respect to capillary porosity. The 80:20 root zone had lower capillary porosity on the final six sampling dates compared to the other two root zones.

In regards to air-filled porosity, the first three sampling dates resulted an inverse relationship between the amount of fines and the amount pore space. The final four sampling dates there were so significant differences between the 80:10:10 and the native root zone and the 80:20 root zone always had higher air-filled porosity.

INTRODUCTION

Links is defined as "a stretch of rolling, sandy land, especially along a seashore" and it was in this environment on these types of soils that golf originated. As golf grew in popularity courses moved inland and problems, most notably drainage, were a concern on the heavy soils [Hutchinson, 1906]. Since really good greens could only be found naturally on sandy soils it was a common practice to topdress inland greens with sand to make them impervious to wear [Travis, 1901]. In the event that the inland native grasses were too coarse, and sod was not available, it became essential to construct a good root zone. In this scenario a 1901 putting green construction recommendation was to "plough up the surface to a depth of a foot, remove loose materials and fill with a few inches of sand, cover with an inch of loam, then a thin crust of well-rotted manure, another layer of loam (2-3") a dressing of bone dust and lime, cover this with a suggestion of sand, and top off with loam, the surface being raked and finely pulverized" [Travis, 1901]. From these early suggestions a standard 1-1-1 (sand-soil-organic v/v) ratio came about in the 1920s-30s [Hummel, 1993].

Prior to World War II the compaction problem of high clay content golf greens was not an issue because traffic was light. However, after the war golf became increasingly popular which resulted in increased traffic and public demand for high quality turf greens [Beard, 1994]. It became apparent that soil greens could not hold up under the increased traffic and it was also determined that equal volumes of sand, soil, and peat did not posses adequate permeability [Garman, 1952]. Thus, the 1950's became a decade of much research that ultimately led to the development of United States Golf Association (USGA) Green Section Specifications [Hummell, 1993].

The USGA published their recommendations for putting green construction in 1960 [USGA Green Section Staff, 1960]. The recommendations were a departure from the norm as they advocated the use of a perched water table to insure a continuous supply of water and physical analysis of the topsoil mixture with specified micropore and macropore space capacities [Radko, 1973]. Since its inception these recommendations have gone through three revisions, the latest of which occurred in 1993 [Hummell, 1993]. However, the basis for the USGA method that has remained constant is that sand based root zone mixtures overlay a coarse sand and/or pea gravel layer. Particle-size range of the root zone mixture is the primary property specified within the USGA specifications because of its influence on soil behavior. These specifications include a maximum of particles in the medium and coarse sand size while minimizing the very coarse and fine sized particles. This produces a root zone mixture that will maintain a large proportion of macropores that allow rapid water movement and drainage. Since these putting greens have an inherently low plant available water holding capacity, different materials (root zone, intermediate layer, and gravel) are stratified, or layered, to increase the ability of the sandy root zone mixture to hold plant available water.

Some advocate the USGA method is suitable for golf courses around the world, others have considered the need for regionalized recommendations, while others still argue that it is totally unnecessary to have a sand green in any form [Beard, 1994, Kussow, 1991, Anonymous, 1994]. Though the USGA method has proven effective over time, some problems continue to occur that have led to questions regarding the USGA method, including cost, increased turfgrass disease, black layer, growth of algae, dry spots, and nutrient deficiencies [Arthur, 1994, Anonymous, 1994, Lucas, 1995].

Reasons for failure of USGA greens have generally been blamed on poor adherence to recommendations, faulty construction techniques, and poor greens management [Griffin, 1966, Kussow, 1991]. Research that is urgently needed for USGA greens include ball roll distance, water content in soil texture, and detailed nutrient management studies [Kussow, 1995]. Furthermore, there remains a difficulty in managing sand based greens due to the accumulation of organic matter in the surface layer [Gibbs et al., 2001].

Though numerous greens have been constructed fitting the USGA recommendations there has been little research reported of comparisons of USGA specification putting greens to other putting green construction methods because of the difficulty in the experimental design and replication necessary to draw valid statistical conclusions [Lodge *et al.* 1991, Lodge and Dawson 1993]. The comparison of differently constructed greens that are sand topdressed is vital, particularly in light of the number of courses with more than one type of green construction present and the widely accepted practice of sand topdressing [Rieke, 1994]. Additionally, the practice of lightweight rolling has increased due to the demand for increased greens speeds [Hartwiger, 1996]. However, the literature is sparse on rolling studies and no long term studies have been performed to address the impact that rolling may have on soil physical properties in different root zones.

The objective of this research was to document post grow-in (changes which occur in greens constructed with three different root zone mixes 3-7 years after establishment) and the effect of rolling for differences in soil physical properties and nitrogen content on greens that were on a light frequent sand topdressing program

MATERIALS AND METHODS

The research was conducted at the Hancock Turfgrass Research Center on the campus of Michigan State University, East Lansing, Michigan on a 1,388 m^2 (36.6 x 36.6m) experimental putting green constructed in summer 1992 and seeded with 'Penncross creeping bentgrass (*Agrostis palustris* Huds.) in spring 1993. The three root zone mixes were: an 80:20 (sand: peat v/v) mixture constructed to USGA recommendations; an 80:10:10 (sand: soil: peat v/v) mixture 0.3m deep built with subsurface tile drainage; and an undisturbed sandy clay loam (58% sand, 20.5% silt, and 21.5% clay) native soil green. The cation exchange capacities of the root zones were 5.8, 6.7, and 9.6 me/100g, respectively. Michigan peat was used in both sand mixes. The particle size analyses for the 80:20 and the 80:10:10 root zone mixes are in Table 1. Both root zones were within USGA particle size specifications for putting green root zone mixes.

Each putting green was 148.8 m^2 (12.2 x12.2 m) arranged in a randomized complete block design with three replications of each green. They were constructed with the specific purpose of comparing among different root zones managed under similar management regimes and each green had four Rain Bird Maxi Paw irrigation heads model number 2045A (Rain Bird Distribution. Co. CA) at the corners for individual plot irrigation

The experimental design for soil physical properties was a split-plot, randomized complete block design with three replications. Main plots were root zone mixes split for rolling. Each green was split into two 10.4 x 5.2m greens that were mowed at sunrise at

0.4cm cutting height six times per week with a walk-behind Toro GM 1000 (Bloomington, MN) greens mower.

One green from each root zone was randomly selected and rolled three times per week (Monday, Wednesday, Friday) with an Olathe (Olathe Manufacturing Inc., Industrial Airport KS) lightweight green roller Model 396 from May through October 1997-2000. The other green in the same root zone block was not rolled and was utilized as a check. The Olathe roller had three smooth rollers that were 980 mm in length and 150 mm in diameter. The machine weighed 427 kg without an operator.

Sand topdressing was applied on the entire area since establishment. Applications were made bi-tri weekly, depending upon growth, from May to September resulting in approximately 6mm applied each year. Additionally, no vertical mowing or core cultivation occurred on the research plots prior to or during the study.

Each green had a $58.2m^2$ destructive sampling area devoted to analysis of soil physical properties. Annual amounts of N-P_2O_5-K_2O applied to the destructive sampling area are reported in Table 2. Methylene urea applied as Nutralene 40-0-0 (The Andersons, Maumee, OH) was the nitrogen source during the warmer months with urea applications made in May and November of each year. Triple superphosphate (0-46-0) was the phosphorous source and potassium sulfate (0-0-50) was the potassium source.

In 1996-97 traffic was applied on all plots with a Toro Greensmaster 3000 (Bloomington, MN) triplex mower fitted with rollers in place of the cutting units. Six mm metal golf shoe spikes were welded onto the rollers. It was estimated that two passes equated to 150 rounds of golf played within 60cm diameter of the golf hole. The estimation was made by counting the number of foot steps taken by golfers in that area, counting the number of spikes on the bottom of a typical golf shoe, and associating that with the number of spikes on the traffic simulator [Hardy, 1999]. During 1996-97 two passes were made with the traffic simulator five times per week. This method of simulating traffic put stress on the mower engine causing termination of this method of traffic simulation in 1998. From 1998-2000 no traffic was simulated on the plots.

In October of each year (1997-2000) three sub-samples were obtained with a 3.2cm diameter soil probe to monitor the percentage of organic matter and total nitrogen from three depths from each root zone. These depths included the sand topdress layer (STL) with the verdure removed which changed in thickness over time (Figure 1) 0-7.6cm, and 7.6-15.2cm below the STL.

The organic matter content (OMC) was determined by loss on ignition as described by Combs and Nathan [1998]. Total nitrogen was determined by the Kjeldahl method with K_2SO_4 + 150 mg $CuSO_4$ used as the catalyst [Bremner, 1965]. In 1999 and 2000 cores were also analyzed for inorganic forms of nitrogen. Ammonium was determined in KCl extracts of soils by the salicylate method [Nelson, 1983] and NO_3-N was determined by the automated Cu-Cd reduction procedure adapted for soil analysis from EPA method no. 353.2 (USEPA, 1983) and the American Public Health Association Standard method no. 4500-NO3-F (APHA, 1989) [Bundy and Meisinger, 1994].

In June of 1998-2000 and the October 1997-2000 four soil cores were obtained from each root zone replication for soil physical property observations. Cores were obtained from the destructive sampling area with the location of core removal recorded on a grid to avoid sampling from a previously disturbed area. Cores were obtained by hammering a 7.6cm diameter cylinder 7.6cm tall into the soil. Cores were removed from the soil and the verdure removed. In the lab cores were inverted and excess soil was removed with a knife making the soil level with the bottom of the metal cylinder. A double layer of cheesecloth was placed on the soil and held on with a rubber band to retain soil in the core. Cores were placed upright and a hollow plastic ring 2.5 cm high x 7.6 cm inside diameter was taped on top of the metal ring. Cores were placed in a bath of distilled water and saturated from below. Soil cores were analyzed for soil bulk density, saturated hydraulic conductivity, capillary, air-filled and total porosity. United States Golf Association specified laboratory methods for the evaluation of putting green root zone mixes were followed with the exception of total porosity [Hummel, 1993]. Total porosity was determined by difference in weight between the saturated soil cores and oven dry cores divided by the core volume [Foth, 1990]. The actual formula used was (((saturated weight (g) – tare (g)) – (oven dry weight (g) – tare (g))) * 100) / 346. This method was utilized because particle density was not determined for each root zone. Particle density was not determined because the STL accumulated over the years taking up continually more core volume that would change the overall particle density.

Analyses of variance were performed on pooled measurements followed by Fischer's protected Least Significant Difference (LSD) if differences were found at $P \geq 0.05$. The LSD was used to compare differences of mean numbers among the different treatments. All data were analyzed using MSTAT [1993].

Table 1. Particle size analysis of root zones mixes and topdressing sand.

	Gravel	Very Coarse	Coarse	Medium	Fine	Very Fine	Silt & Clay
	Description						
	Diameter (mm)						
	>2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	<0.05
Mixture	Percentage of each diameter size retained on each sieve (by weight)						
80:20	0.2	4.8	34.6	46.7	12.2	0.9	0.6
80:10:10	1.9	6.8	31.1	40.4	16.6	1.9	1.3
Topdress	0.0	2.8	30.6	48.4	17.3	0.6	0.3

Table 2. Annual rates of nutrients applied to the destructive sampling area for the analysis of soil physical properties.

	kg ha^{-1}		
	Nitrogen	P_2O_5	K_20
1996	170	49	98
1997	170	0	98
1998	170	98	0
1999	146	98	0
2000	146	0	122

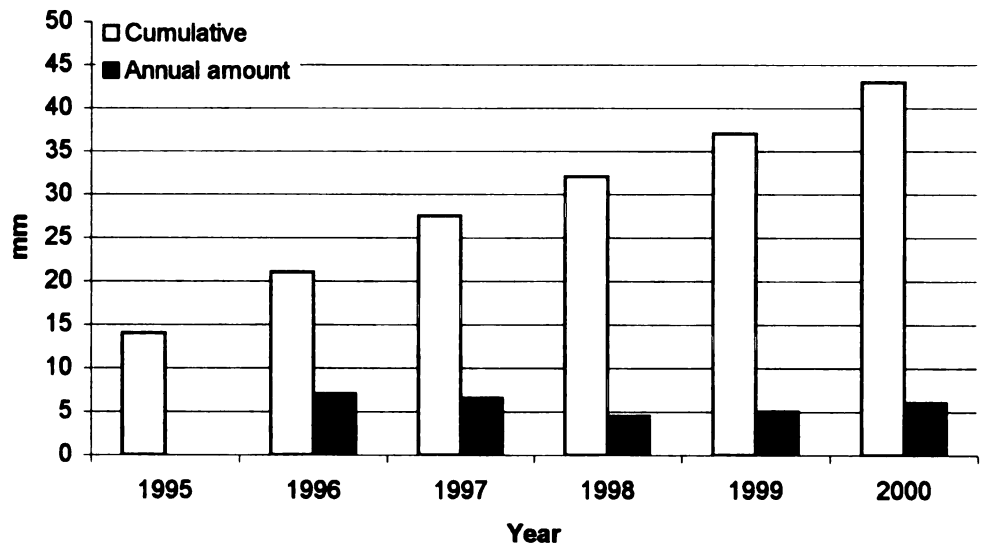

Figure 1. Accumulation of sand topdressing layer on *Agrostis palustris* Huds. greens annually measured in October, East Lansing, MI.

RESULTS AND DISCUSSION

Organic Matter Content

The organic matter content (OMC) in the three different root zones is reported in Tables 3-5. Data from 1999 was discarded due to apparent erroneous results. In Table 3 the OMC in the sand topdressing layer (STL) is given. Since the STL is the same soil texture in all root zones no differences were anticipated and no significant differences occurred.

The 0-7.6cm depth below the STL soil interface is reported in Table 4. Within that depth the native root zone had significantly more OMC than the other two root zones in 1998. The other two years the data was not statistically significant.

The OMC in the 7.6-15.2 cm depth (Table 5) had similar results to that of the 0-7.6cm depth with 1998 the only year resulting in significantly more OMC in the native root zone. Since the native soil root zone was undisturbed (located where it had vegetative cover previous to green construction) and the other two root zones were transported in, it is reasonable the native soil root zone would have a higher OMC below the STL.

OMC was further analyzed split for time. Data analyzed in this manner are presented in Table 6. Again, no significant differences were observed in OMC in the STL among the root zones and the native root zone had more OMC in the 0-7.6cm depth than the 80:20 root zone. There were no significant differences between the 80:20 and 80:10:10 root zones. Furthermore, the OMC increased with time in the STL with no significant data or trends resulting in the other two depths.

Foth [1990] states soil organic matter can decompose in mineral soils at a rate of up to 4% per year. However, over time plant residues are expected to maintain OMC at a new equilibrium. Below the STL none of the root zones significantly changed over the four-year period. Other research monitoring OMC over time in predominantly sand based greens report mixed results with increases, decreases, and no significant change several years after establishment [Baker et al., 1999, Werner, 1995, Landry et. al., 2001, Gibbs et al., 2001].

Table 3. Main effects and mean squares for treatment effects of root zone on percentage organic matter in the topdress layer 1997, 1998, and 2000.

		Percentage organic matter		
Root zone		Oct. 1997	Oct. 1998	Oct. 2000
80:20		2.70	2.98	3.28
80:10:10		2.94	2.95	3.61
Native		3.24	3.32	3.91
Significance		NS	NS	NS
Source	df		Mean square	
Replication	2	0.340*	0.088	0.020
Soils	2	0.217	0.125	0.295
Error	4	0.035	0.061	0.166

* Significant at the 0.05 probability level.

† NS, nonsignificant at the 0.05 level.

Table 4. Main effects and mean squares for treatment effects of root zone on percentage organic matter 0-7.6cm below the topdressing soil interface 1997, 1998, and 2000.

		Percentage organic matter		
Root zone		Oct. 1997	Oct. 1998	Oct. 2000
80:20		1.59	1.56b	1.61
80:10:10		1.91	1.78b	2.20
Native		2.45	2.49a	2.60
Significance		NS	**	NS
Source	df		Mean square	
Replication	2	0.120	0.122	0.375
Soils	2	0.858	0.703**	0.744
Error	4	0.174	0.026	0.163

** Significant at the 0.01 probability level.

† NS, nonsignificant at the 0.05 level.

Table 5. Main effects and mean squares for treatment effects of root zone on percentage organic matter 7.6-15.2 cm below the topdressing soil interface 1997, 1998, and 2000.

		Percentage organic matter		
Root zone		Oct. 1997	Oct. 1998	Oct. 2000
80:20		1.09	1.15b	1.18
80:10:10		1.34	1.50b	1.55
Native		2.12	2.31a	2.22
Significance		NS	*	NS
Source	df		Mean square	
Replication	2	0.024	0.065	0.351
Soils	2	0.559	1.062*	0.830
Error	4	0.144	0.107	0.160

*, ** Significant at the 0.05 and 0.001 probability levels, respectively.
† NS, nonsignificant at the 0.05 level.

Table 6. Main effects and mean squares for treatment effects of root zone split for time on percentage organic matter at three depths 1997, 1998, and 2000.

		Percentage organic matter by depth		
Root zone		Sand topdressing	0-7.6 cm	7.6-15.2cm
80:20		2.99	1.59b	1.14
80:10:10		3.17	1.96ab	1.46
Native		3.49	2.51a	2.22
Significance		NS	*	NS
Year				
1997		2.96b	2.05	1.55
1998		3.08b	1.88	1.62
2000		3.60a	2.14	1.65
Significance		**	NS	NS
Source	df			
Replication		0.047	0.298	0.401
Soils		0.579	1.920*	2.713
Error		0.172	0.296	0.451
Year		1.033**	0.085	0.031
Soils x Year		0.029	0.040	0.005
Error		0.097	0.078	0.026

*, ** Significant at the 0.05 and 0.001 probability levels, respectively.
† NS, nonsignificant at the 0.05 level.

Nitrogen

Total soil nitrogen is mainly comprised of organic compounds that occur as consolidated amino acids or proteins, free amino acids, amino sugars, and other complex, generally unidentified compounds [Tisdale *et al*, 1985]. Total-N in the three different root zones is reported in Tables 7-9. Total-N in the STL layer is significantly different for the root zones in 1998 (Table 7). The native soil had significantly greater total-N than the other two root zones in this surface layer.

In Table 8 total-N in the 0-7.6cm depth below the STL layer is reported. Within that depth the native soil had significantly more total-N three of the four years compared to the 80:20 root zone and also had significantly greater total-N than the 80:10:10 mix two of the years.

Total N in the 7.6-15.2 cm below the topdressing soil interface was always significantly greater in the native soil than the other two root zones (Table 8). No statistical differences resulted between either of the predominantly sandy root zones at any depth.

Total nitrogen concentrations in the top 0.3m of cultivated soils in the United States normally vary between 0.03 and 0.4% [Tisdale *et al*, 1985]. The native root zone was consistently within this range. The 80:20 fell slightly below it in 1998 and 2000 at depths below the STL and the 80:10:10 fell below it in 1998 in the 0-7.6cm depth.

Table 7. Main effects and mean squares for treatment effects of root zone on percentage total nitrogen in the topdress layer 1997-2000.

		Percentage total nitrogen			
Root zone		Oct. 1997	Oct. 1998	Oct. 1999	Oct. 2000
80:20		0.12	0.05b	0.08	0.11
80:10:10		0.11	0.05b	0.09	0.11
Native		0.12	0.10a	0.12	0.13
Significance		NS	*	NS	NS
Source	df	Mean square			
Replication	2	0.001	0.000	0.000	0.001
Soils	2	0.000	0.002*	0.001	0.000
Error	4	0.001	0.0003	0.0003	0.001

* Significant at the 0.05 probability level.

† NS, nonsignificant at the 0.05 level.

Table 8. Main effects and mean squares for treatment effects of root zone on percentage total nitrogen 0-7.6cm below the topdressing soil interface 1997-2000.

		Percentage total nitrogen			
Root zone		Oct. 1997	Oct. 1998	Oct. 1999	Oct. 2000
80:20		0.04b	0.02b	0.04	0.01b
80:10:10		0.06b	0.02b	0.05	0.04ab
Native		0.11a	0.11a	0.07	0.09a
Significance		*	*	NS	*
Source	df	Mean square			
Replication	2	0.000	0.001	0.004	0.001
Soils	2	0.004*	0.009*	0.001	0.006
Error	4	0.0003	0.001	0.001	0.001

** Significant at the 0.01 probability level.

† NS, nonsignificant at the 0.05 level.

Table 9. Main effects and mean squares for treatment effects of root zone on percentage total nitrogen 7.6-15.2 cm below the topdressing soil interface 1997-2000.

		Percentage total nitrogen			
Root zone		Oct. 1997	Oct. 1998	Oct. 1999	Oct. 2000
80:20		0.03b	0.01b	0.05b	0.001b
80:10:10		0.04b	0.03b	0.05b	0.009b
Native		0.09a	0.11a	0.11a	0.088a
Significance		*	**	**	*
Source	df	Mean square			
Replication	2	0.000	0.000	0.001	0.001
Soils	2	0.003*	0.007**	0.003**	0.007*
Error	4	0.0005	0.0003	0.0001	0.001

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

About 90% of soil N is unavailable in organic matter with most of the remainder fixed as ammonium in clays and at any one instant about 1% or less of the total-N in soils is available to plants as nitrate or exchangeable ammonium [Foth and Ellis, 1997].

In 1999 and 2000 inorganic forms of nitrogen in the root zones were analyzed and are reported in Tables 10 and 11, respectively. No significant differences occurred in the STL.

In 1999 significantly more NO_3-N was in the 0-7.6 cm depth in the native soil than in the 80:10:10 root zone with no difference between the 80:10:10 and the 80:20. In 2000 there was more NH_4-N at this depth in the native soil than in the sandy root zones.

In the 7.6-15.2 cm depth there was significantly more NH_4-N in the native soil than the other two root zones during both years. The only significant difference between the 80:20 and 80:10:10 regarding inorganic nitrogen pools was that 80:10:10 held significantly more NH_4-N than the 80:20 root zone in the 7.6-15.2 cm depth in 2000.

Nitrate-N and NH_4-N decreased with depth in the 80:20 root zone and increased with depth in the native soil, for both years of data collection. Certainly soil nitrogen is dynamic in a relatively short period of time and data reported here only reflects a snapshot in time. Therefore, it would be erroneous to make strong conclusions regarding NO_3-N in the 80:20 root zone, but similarly it would be shortsighted to ignore that nitrates did not increase with depth in the 80:20 root zone. Rieke and Ellis [1973] researched N leaching in a sand texture and concluded when judicious nitrogen rates are applied the potential for appreciable leaching of NO_3-N would be limited under most turfgrass conditions. Additionally, Brown *et al* [1982] reported methylene urea resulted in less NO_3-N leaching than four other nitrogen fertilizers in their study on USGA-type profiles and that ammonium losses contributed very little to N losses from golf greens.

Though not always significant, a trend is evident that ammonium nitrogen in the 80:20 < 80:10:10 < native root zone below the STL. This would be expected due to the cationic nature of NH_4-N allowing it to be adsorbed and retained by soil colloids [Tisdale *et al.*, 1985].

Table 10. Main effects and mean squares for treatment effects of root zone on inorganic forms of nitrogen at various depths (October 1999).

		Inorganic N forms at three depths in ppm					
		Topdress layer		0-7.6cm depth		7.6-15.2cm depth	
Root zone		NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
80:20		0.47	8.35	0.25ab	5.81	0.14	3.82b
80:10:10		0.72	10.42	0.04b	6.25	0.40	6.96b
Native		0.72	15.04	0.74a	14.01	0.79	16.70a
Significance		NS	NS	*	NS	NS	**
Source	df	Mean squares					
Replication	2	0.698	14.22	0.147	8.12	0.010	5.94
Soils	2	0.063	35.25	0.382*	63.78	0.32	135.36**
Error	4	0.091	8.64	0.051	11.76	0.21	4.41

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
† NS, nonsignificant at the 0.05 level.
‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 11. Main effects and mean squares for treatment effects of root zone on inorganic forms of nitrogen at various depths (October 2000).

		Inorganic N forms at three depths in ppm					
		Topdress layer		0-7.6 cm depth		7.6-15.2 cm depth	
Root zone		NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
80:20		0.59	11.42	0.39	4.87b	0.32b	3.23c
80:10:10		0.45	9.28	0.44	10.28b	0.48ab	8.21b
Native		0.52	9.94	0.56	21.86a	0.74a	16.18a
Significance		NS	NS	NS	*	*	***
Source	df	Mean squares					
Replication	2	0.03	9.73	0.03	26.64	0.03	3.05
Soils	2	0.01	3.63	0.02	225.99*	0.13*	127.89***
Error	4	0.02	8.74	0.02	22.21	0.02	0.82

*, *** Significant at the 0.05 and 0.001 probability levels, respectively.
† NS, nonsignificant at the 0.05 level.
‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Saturated Hydraulic Conductivity

Saturated hydraulic conductivity, bulk density, and soil porosities were collected from non-rolled and rolled plots and were analyzed as a two-factor study (root zone split by rolling). In Table 12 the saturated hydraulic conductivity (K_{sat}) of the root zones is reported. As is often the case with field samples taken to the lab for hydraulic conductivity, there was a high degree of variability in the data. For all seven dates the

80:20 mix had significantly faster conductivity rates than the native root zone and was significantly faster than the 80:10:10 root zone on six of those seven dates. The last five of the seven dates there were no significant differences between the 80:10:10 and the native root zones.

Plots rolled three times per week always resulted in averaged conductivity rates lower than non-rolled plots however; none of the data was statistically significant.

Bulk Density

Soil bulk density measurements revealed relatively small differences among the three different root zones (Table 13). Coarse-textured surface soils are expected to have higher bulk densities than finer-textured soils due to the greater development of structure in the fine-textured soils [Foth, 1990]. Possibly due to the destruction of structure and compaction by machinery during construction the predominantly sandy 80:20 root zone had a significantly lower bulk density than the native root zone on 5 of the 7 sampling dates.

Lightweight rolling resulted in no significant differences regarding soil bulk density in any of the root zones. Nikolai *et al.* [2001] reported similar results on greens rolled three times per week but that data was from one year.

Table 12. Main effects and mean squares for treatment effects of root zone and rolling on saturated conductivity 1997-2000.

		Saturated conductivity, cm hr^{-1}						
Root zone		Oct. 97	June 98	Oct. 98	June 99	Oct. 99	June 00	Oct. 00
80:20		15.5a	29.9a	21.3a	17.2a	12.3a	15.1a	29.7a
80:10:10		8.6b	13.4b	8.3b	7.2b	4.2b	5.2b	8.2ab
Native		3.4c	5.3c	0.6b	0.6b	1.6b	1.6b	1.4b
Significance		***	**	**	*	*	*	*
Rolling								
Rolled		6.7	14.4	5.8	7.1	4.7	4.0	9.5
Not Rolled		11.7	17.9	14.3	9.6	7.4	10.6	16.7
Significance		NS†	NS	NS	NS	NS	NS	NS
Source	df	Mean square						
Replication	2	86.3	18.7	92.8	100.3	32.9	53.9	457.4
Soils	2	223.5***	948.5**	663.4**	417.3*	190.0*	294.1*	1310.6*
Error	4	3.7	24.4	34.5	31.9	22.7	29.6	185.9
Rolling	1	114.0	56.9	329.4	28.6	32.3	194.0	229.0
Soil X Rolling	2	4.3	2.2	141.9	8.5	17.1	50.0	122.2
Error	6	88.2	23.6	86.6	49.6	17.7	34.8	91.2

*, **, *** Significant at the 0.05 0.01, and 0.001 probability levels, respectively.
† NS, nonsignificant at the 0.05 level.

Table 13. Main effects and mean squares for treatment effects of root zone and rolling on soil bulk density 1997-2000.

		Soil bulk density, g cc^{-1}						
Root zone		Oct. 97	June 98	Oct. 98	June 99	Oct. 99	June 00	Oct. 00
80:20		1.5b	1.5b	1.55b	1.5b	1.5	1.5	1.42b
80:10:10		1.5b	1.5b	1.58ab	1.5b	1.5	1.5	1.47ab
Native		1.6a	1.6a	1.67a	1.6a	1.6	1.5	1.55a
Significance		*	*	*	*	NS	NS	*
Rolling								
Rolled		1.6	1.5	1.60	1.5	1.5	1.5	1.48
Not Rolled		1.5	1.5	1.60	1.5	1.5	1.5	1.48
Significance		NS†	NS	NS	NS	NS	NS	NS
Source	df	Mean square						
Replication	2	0.007	0.002	0.007	0.004	0.004	0.002	0.017
Soils	2	0.041*	0.020*	0.022*	0.017*	0.024	0.011	0.027 *
Error	4	0.005	0.002	0.003	0.001	0.006	0.008	0.003
Rolling	1	0.002	0.000	0.000	0.001	0.005	0.009	0.000
Soil X Rolling	2	0.001	0.000	0.002	0.004	0.002	0.001	0.002
Error	6	0.001	0.002	0.001	0.001	0.001	0.002	0.001

*Significant at the 0.05 probability level.
† NS, nonsignificant at the 0.05 level.

Porosity

Capillary, air-filled and total porosities are reported in Tables 14-16, respectively. On 6 of the 7 sampling dates capillary porosity was significantly lower for the 80:20 root zone than the other two root zones with no significant differences between the 80:10:10 and the native root zones (Table 14). Lightweight rolling had no statistically significant effect on capillary porosity though on all dates capillary porosity was higher on plots rolled three times per week.

The 80:20 root zone had significantly higher air-filled porosities than the other two root zones on all sampling dates (Table 15). The 80:10:10 root zone was significantly higher than the native root zone on the first three dates but no significant differences resulted between the two root zones for the last four dates. Lightweight rolling resulted in significant reduction in air-filled porosity on the final three of seven sampling dates. No soils by rolling interactions were significant.

Total porosity is reported in Table 16. Only three of the dates resulted in significant differences with the native root zone always resulting in less total porosity than the 80:20 mix. On three of the seven sampling dates total porosity was significantly lower on rolled plots

Table 14. Main effects and mean squares for treatment effects of root zone and rolling on capillary porosity at 40 cm 1997-2000.

		Capillary porosity at 40 cm tension						
Root zone		Oct. 97	June 98	Oct. 98	June 99	Oct. 99	June 00	Oct. 00
80:20		25.2	27.9b	24.5b	26.4b	24.0b	24.5b	25.4b
80:10:10		30.0	33.4a	30.5a	33.1a	31.1a	31.3a	33.1a
Native		33.0	33.9a	32.3a	34.1a	33.6a	33.8a	32.7a
Significance		NS	**	**	**	**	**	**
Rolling								
Rolled		30.0	32.3	30.1	31.8	30.4	30.6	31.4
Not Rolled		28.7	31.3	28.2	30.6	28.7	29.1	29.3
Significance		NS	NS	NS	NS	NS	NS	NS
Source	df	Mean square						
Replication	2	40.42	21.43	24.20	38.44*	40.01*	35.28	35.56*
Soils	2	93.13	67.05**	99.99**	106.92**	149.69**	139.91**	113.43**
Error	4	19.29	4.55	4.60	5.39	5.87	5.72	5.18
Rolling	1	7.48	4.70	16.06	7.60	12.67	9.68	19.84
Soil X Rolling	2	14.58	14.36	13.58	7.80	22.46	16.95	19.42
Error	6	6.60	9.95	7.45	10.23	6.61	5.12	6.45

*Significant at the 0.05 probability level.

† NS, nonsignificant at the 0.05 level.

Table 15. Main effects and mean squares for treatment effects of root zone and rolling on air-filled porosity at 40 cm tension 1997-2000.

		Air-filled porosity at 40 cm tension						
Root zone		Oct. 97	June 98	Oct. 98	June 99	Oct. 99	June 00	Oct. 00
80:20		22.4a	17.5a	17.4a	18.3a	20.3a	19.0a	19.2a
80:10:10		15.7b	10.6b	10.8b	11.3b	12.1b	12.3b	11.2b
Native		10.0c	7.1c	7.0c	8.5b	9.9b	9.6b	12.7b
Significance		**	***	**	**	**	**	**
Rolling								
Rolled		14.5	9.4	10.4	11.6	12.3	12.1	13.1
Not Rolled		17.6	11.3	13.1	13.9	15.9	15.2	15.6
Significance		NS	NS	NS	NS	**	*	*
Source	df	Mean square						
Replication	2	36.97	11.32	14.47	20.74	25.01	29.53*	16.86
Soils	2	234.20	183.52***	164.28**	153.30**	180.88**	138.94**	107.55**
Error	4	12.39	2.91	5.40	5.27	11.41	3.31	6.34
Rolling	1	43.24	16.82	32.00	24.73	58.68**	44.18*	28.12*
Soil X Rolling	2	9.31	10.62	10.63	5.25	11.68	10.94	4.08
Error	6	9.47	7.86	7.57	9.78	2.83	4.62	4.66

*Significant at the 0.05 probability level.

† NS, nonsignificant at the 0.05 level.

Table 16. Main effects and mean squares for treatment effects of root zone and rolling on total porosity 1997-2000.

		Total porosity						
Root zone		Oct. 97	June 98	Oct. 98	June 99	Oct. 99	June 00	Oct. 00
80:20		47.7a	45.4a	41.9	44.7a	44.3	43.4	44.5
80:10:10		45.8b	44.1ab	41.3	44.3a	43.3	43.5	44.3
Native		42.9c	41.1b	39.3	42.6b	43.5	43.4	45.4
Significance		**	*	NS	*	NS	NS	NS
Rolling								
Rolled		44.6	42.9	40.5	43.4	42.7	42.6	44.5
Not Rolled		46.3	44.2	41.2	44.5	44.7	44.3	45.0
Significance		NS	NS	*	NS	*	*	NS
Source	df	Mean square						
Replication	2	1.24	5.17	6.20	3.84	4.79	3.63	9.62
Soils	2	35.42**	29.69*	10.56	7.53*	1.74	0.03	1.97
Error	4	1.14	4.28	1.69	1.14	6.11	5.59	6.95
Rolling	1	12.84	7.35	2.42*	4.91	17.01*	12.67*	0.89
Soil X Rolling	2	2.35	1.38	0.76	0.66	6.33	1.03	6.07*
Error	6	2.84	3.71	0.33	1.64	1.60	1.32	0.80

*Significant at the 0.05 probability level.

† NS, nonsignificant at the 0.05 level.

CONCLUSIONS

A problem associated with sand based greens is difficulty in managing the accumulation of organic matter in the surface layer [Gibbs et al., 2001]. There were no significant differences among the root zones in accumulation of organic matter in the STL and data pooled among root zones resulted in OMC significantly increasing in the STL over time. There were no root zones x time interactions. In the 0-7.6cm depth the native root zone had a significantly greater OMC than the 80:20 root zone. However, the OMC did not significantly increase in that depth over time.

In all years and depths total-N was greater in the native root zone than the 80:20 root zone with no significant differences occurring between the predominantly sandy root zones. Nitrate-N decreased with depth in the 80:20 root zone. This decrease supports the notion that judicious rates of slow release nitrogen sources are not necessarily leached from sandy profiles. The 80:10:10 root zone did not result in greater total-N or NO_3-N in the soil and on only one occasion did it have greater retention of NH_4-N.

The 80:20 root zone had significantly higher saturated hydraulic conductivity rates than the 80:10:10 root zone on all but one date and it was consistently higher than the native root zone on all dates. There were no significant differences between the 80:10:10 and the native root zone during the last five sampling dates.

No significant differences resulted between the 80:10:10 and the native root zones in respect to capillary porosity. The 80:20 root zone had lower capillary porosity on the final six of seven sampling dates.

In regards to air-filled porosity, the first three sampling dates resulted an inverse relationship between the amount of fines and the amount pore space. The final four sampling dates there were no significant differences between the 80:10:10 and the native root zone and the 80:20 root zone always had higher air-filled porosity. Though there is no statistically significant data it is noteworthy the practice of sand topdressing may have had an effect on diminishing significant differences of saturated hydraulic conductivity and air-filled porosity between the 80:10:10 and the native root zones.

Lightweight green rolling three times per week resulted in no significant differences in bulk density, capillary porosity, or saturated hydraulic conductivity. Significant differences included air-filled porosity reduction on the last three sampling dates and reduced total porosity on 3 of seven sampling dates. It is noteworthy that while there were no increases in bulk density associated with rolling, all plots were on a light, frequent sand topdressing program. Had greens not been on a sand topdressing program increases in bulk density may have resulted

REFERENCES

Anonymous. 1994. Expensive sand greens not necessary, argues proponent of new system. Turf Management. August p.3.

Arthur, J. 1994. Who needs performance standards? Turf Management. May p. 11.

Baker, S. W., S. J. Mooney, and A. Cook. 1999. The effects of sand type and rootzone amendments on golf green performance. I. Soil properties. J. of Turfgrass. Science. 75:2-17.

Beard, J. 1994. In search of the ultimate putting green. Greenkeeper Int. December:22-25.

Bremner, J. M. 1965. Total nitrogen. p.1149-1178. *In* C. A. Black et al. (ed.) Methods of soil analysis. Part 2. Agron. Monogr. 9. ASA, Madison, WI.

Brown, K. W., J. C. Thomas, and R. L. Duble. 1982. Nitrogen source effect on nitrate and ammonium leaching and runoff losses from greens. Agronomy Journal 74(6):947-950.

Bundy, L. G. and J. J. Meisinger. 1994. p. 951-984. In J. M. Bigham et al. (ed) Methods of soil analysis. Part 2. Agron. Monogr. ASA, Madison, WI.

Combs, S. M. and M. V. Nathan. 1998. Soil organic matter. P.53-58. *In* B. Ellis et al. Recommended chemical soil test procedures for the north central region. Missouri Agri. Expe. Sta. Columbia, MO.

Foth H. D. and B. G. Ellis. 1997. Soil Fertility 2nd Ed. Lewis Publishers Boca Raton, FL.

Foth H. D. 1990. Fundamentals of soil science 8th Ed. John Wiley & Sons. New York.

Garman, W. L. 1952. Permeability of various grades of sand and peat and mixtures of these with soil and vermiculite. USGA J. Turf Manag. 6(1):27-28.

Gibbs, R. J., C. Liu, M.-H. Yang, and M.P. Wrigley. 2001. Effect of rootzone composition and cultivation/aeration treatment on the physical and root growth performance of golf greens under New Zealand conditions. Int. Turfgrass Soc. Res. J. 9:506-517.

Griffin, H. M. 1966. Recipe for good greens. USGA Green Section Record. 3(5):1-2.

Hardy, J. A. 1999. Factors affecting creeping bentgrass quality of three different putting green construction methods. M.S. Thesis. Michigan State University.

Hartwiger, C. 1996. The ups and downs of rolling putting greens. USGA Green Section Record 34(4): 1-4.

Hutchinson, H. G. 1906. Golf greens and green-keeping. Country Life Ltd. & George Newnes, Ltd. London.

Hummel, N. W. 1993. Rationale for the revisions of the USGA green construction specifications. USGA Green Section Record. March/April: 7-21.

Hummel, N. W. 1993. Laboratory methods for evaluation of putting green root zone mixes. USGA Green Section Record. March/April: 23-32.

Kussow, W. R. 1995. Some USGA putting green management issues. The Grass Roots. 23(3):44-45.

Landry, G. and M. Schlossberg. 2001. Bentgrass (*Agrostis* spp.) cultivar performance on a golf course putting green. Int. Turfgrass Soc. Res. J. 9:886-891.

Lodge, T. A., S. W. Baker, P.M. Canaway, and D.M. Lawson. 1991. The construction irrigation and fertilizer nutrition of golf greens. I. Botanical and reflectance assessments after establishment and during the first year of differential irrigation and nutrition treatments. J. Sports Turf Res. Inst. 67:32-43.

Lodge, T. A., and D. M. Lawson. 1993. Sand topdressing: where are we going? The-construction irrigation and fertilizer nutrition of golf greens. Botanical and soil chemical measurements over three years of differential treatment. J. Sports Turf Res. Inst. 69:59-73.

Lucas, L. T. 1995. Diseases of bentgrass on high-sand-content golf green. TurfFiles: NCSU web site. May; 1-3.

MSTAT. 1993. Microcomputer statistical program. Michigan State Univeristy, East Lansing, MI, USA.

Nelson D. W. 1983. Determination of ammonium in KCl extracts of soils by the salicylate method. Commun.in soil sci. plant anal. 14(11), 1051-1062.

Nikolai T. A., P. E. Rieke, J. N. Rogers, III, and J. M. Vargas Jr. 2001. Turfgrass and soil responses to lightweight rolling on putting green root zone mixes. Int. Turf. Soc. Res. J. 9:604-609.

Radko, A. M. 1973. Refining Green Section Specifications for putting green construction. Proc. Sec. Int. Turfgrass Research Con. 287-297.

Rieke, P. E. and B. G. Ellis. 1973. Effects of nitrogen fertilization on nitrate movements under turfgrass. . Int. Turfgrass Soc. Res. J. 2:120-130.

Tisdale S. L., N. L. Werner, and J. D. Beaton. 1985. Soil Fertility and Fertilizers 4^{th} Ed. Macmillan Publishing Company, New York, New York.

Travis, W. J. 1901. Practical Golf. Harper & Brothers. New York.

USGA Green Section Staff. 1960. Specifications for a method of putting green construction. USGA Journal and Turf Management. 13(5):24-28.

Werner, S. 1995. Comparison among golf-green constructions in a field trail. Rasen-Turf-Gazon. 26(4):116-122.

CHAPTER TWO

TURFGRASS RESPONSES TO LIGHTWEIGHT ROLLING ON THREE PUTTING GREEN ROOT ZONE MIXES

ABSTRACT

Three putting green root zones: an 80:20 (sand: peat v/v) mixture constructed to USGA recommendations; an 80:10:10 (sand: soil: peat v/v) mixture 0.3m deep built with subsurface tile drainage; and an undisturbed sandy clay loam native soil green were established to study the effects that rolling and fertility treatments had on the root zones. Rolling treatments consisted of rolled 3x/week and not rolled. Fertility treatments consisted of two nitrogen rates (146 and 293 kg ha^{-1} $year^{-1}$) and three potassium rates (0, 195, and 390 K_2O kg ha^{-1} $year^{-1}$).

Rolling greens three times per week produced greater ball roll distance without detriment to turfgrass quality. Lightweight rolling consistently resulted in less dollar spot (*Sclerotinia homoeocarpa*), most notably in the predominantly sandy root zones. Speculations are made about why lightweight rolling three times per week reduced dollar spot severity. Lightweight rolling also resulted in fewer bird beak intrusions through the turfgrass canopy into the root zone. It is theorized that the reduction may be due to less cutworm activity on rolled greens. Rolled plots also had significantly less broadleaf weeds during the one-year broadleaf weeds were observed on the site.

Color and quality ratings revealed no meaningful differences among the three different root zones. There was an inverse relationship between the amount of fines in the root zone and dollar spot severity. Nitrogen rate consistently resulted in significant

differences in dollar spot counts, but the amount of time that passed after the nitrogen application appeared to be a factor. The higher rate of nitrogen resulted in fewer dollar spot infections when nitrogen fertility averaged 14 days after application. The lower rate of nitrogen resulted in fewer dollar spot infections when nitrogen fertility averaged 32 days after application.

The lower rate of nitrogen had significantly greater ball roll distance than the higher rate of nitrogen. There was also a trend as the difference in ball roll distance increased between the two nitrogen rates with differences of 8cm in 1998, 10 cm in 1999, and 19 cm in 2000.

Significant localized dry spot differences were observed one year. At that time the higher nitrogen rate resulted in a greater percentage of localized dry spot than the lower nitrogen rate. At the higher N-rate localized dry spot was reduced with the practice of rolling. The native soil and 80:20 root zones had more localized dry spot than the 80:10:10 root zone. Potassium had no effect on ball roll distance, dollar spot, color, quality, or localized dry spot.

INTRODUCTION

In 1901 green keeper Walter Travis wrote, "From May until October each green should be rolled daily with a light roller, rather than once or twice a week with a heavy one" [Travis, 1901]." For the next quarter century numerous publications addressed roller frequency, weight, compaction and soil texture [Hutchinson, 1906, Harban, 1922; Piper and Oakley, 1921; Anonymous, 1926] without coming to any clear conclusions. Shortly thereafter, the practice of frequent rolling ceased as turfgrass research showed a link between high levels of soil compaction and turf root growth [DiPaola and Hartwiger, 1994]

The practice of lightweight green rolling returned in the 1990's attributed to the demand for fast ball roll distances. However, concerns that existed in the 1920's remain in that some golf course superintendent's view rolling as a means of improving putting quality, while others believe rolling causes additional stress that makes putting green management more difficult [Hartwiger, 1996]. Besides the near century old concerns regarding compaction, there is also the need to investigate the potential for above ground turfgrass problems associated with continual season-long turf rolling and the possibility that pathogens may invade crushed tissues, leading to diseased turf [Beard, 1994].

To address these questions a lightweight rolling study was initiated at Michigan State University in 1995 on greens constructed with different root zones [Nikolai et al., 2001]. In that study plots were rolled three times per week. Results included significant increases in ball roll distance (BRD) the day of and the day after rolling treatments were applied. Furthermore, rolled plots had significantly less dollar spot (*Sclerotinia homoeocarpa*) than non-rolled plots during the second year of the study and on one occasion rolling resulted in more pink snow mold (*Microdochium*) [Nikolai et al., 2001]. To further investigate the potential impact lightweight rolling had on disease severity it was determined to continue the rolling study four more years. With the continuation of the study, plots were split for nitrogen and potassium rates to address the impact rolling might have on root zones under different fertility programs. The objectives of this portion of the study were to evaluate the effects of season long lightweight green rolling and fertility on ball roll distance, turfgrass color and quality, and disease susceptibility on three putting green root zones.

MATERIALS AND METHODS

The research was conducted at the Hancock Turfgrass Research Center at Michigan State University, East Lansing, Michigan on a 1,388 m^2 (36.6 x 36.6m) experimental putting green constructed in summer 1992, and seeded with 'Penncross creeping bentgrass (*Agrostis palustris* Huds.) in spring, 1993. The three root zone mixes were: an 80:20 (sand: peat v/v) mixture constructed to USGA recommendations; an 80:10:10 (sand: soil: peat v/v) mixture built 0.3m deep with subsurface tile drainage; and an undisturbed sandy clay loam (58% sand, 20.5% silt, and 21.5% clay) native soil green. The cation exchange capacities of the root zones was 5.8, 6.7, and 9.6 me/100g, respectively. Michigan peat was used in both sand mixes. Both sands were within USGA specifications for putting green root zone mixes (Table 1).

Each putting green was 148.8 m^2 (12.2 x12.2 m) and was arranged in a randomized complete block design with three replications of each green. Each 12.2 x 12.2m putting green had four Rain Bird Maxi Paw irrigation heads model number 2045A

(Rain Bird Distribution. Co. CA) at the corners for individual plot irrigation. Irrigation was applied on a daily basis with the exception of dry down periods to permit collection of data on the development of localized dry spot.

The experimental design was a split-split-plot, randomized complete block design with three replications. Main plots were root zone mixes split for rolling (rolled 3x/week and not rolled). Rolling was split for two nitrogen rates and three potassium rates. Greens were constructed with the specific purpose of comparing among different root zones managed under similar management regimes. Each green was split into two 10.4 x 5.2m greens that were mowed at 0.4cm cutting height six times per week with a walk-behind Toro GM 1000 (Bloomington, MN) greens mower.

One green from each construction plot was randomly selected and rolled three times per week (Monday, Wednesday, Friday) with an Olathe (Olathe Manufacturing Inc., Industrial Airport, KS) lightweight green roller Model 396 from May through October 1997-2000. The other green in the same root zone block was not rolled and was utilized as a check. The Olathe roller had three smooth rollers that were 980 mm in length and 150 mm in diameter. The machine weighed 427 kg without an operator.

Fertility treatments consisted of two nitrogen rates (146 and 293 kg ha^{-1} $year^{-1}$) and three potassium rates (0, 195, and 390 K_2O kg ha^{-1} $year^{-1}$). In 1997 individual plots designated as 0 kg ha^{-1} potassium actually received potassium based on October, 1996 soil samples results. No further potassium was applied on the 0 potassium plots in 1998-2000. Each fertility plot was 4.7 m^2 (0.9 x 5.2 m). Fertilizer was applied with a 0.9m width drop spreader. Methylene urea applied as Nutralene 40-0-0 (The Andersons, Maumee, OH) was the nitrogen source during the warmer months with urea applications being made in May and November of each year. Potassium sulfate (0-0-50) was the potassium source. All plots received the same amount of P during the study.

Sand topdressing was applied on all three-root zone mixes on a light, frequent basis throughout the growing season (Figure 1). Additionally, no vertical mowing or core cultivation occurred on the research plots prior to or during the study. Fungicides were applied on a curative basis to allow for disease observations to occur.

Ball roll distance (BRD) measurements were obtained on several dates in 1998-2000 on the day of and the day following rolling treatments. Measurements were initiated approximately 3 and 27 hours after rolling. Measurements were taken with a Stimpmeter in accordance with USGA instructions (USGA Green Section Staff, 1996). Data reported reflect the means of all six numbers across treatments.

Sclerotinia homoeocarpa (dollar spot), broadleaf weed, and bird beak intrusion counts were taken when symptoms occurred by counting the number of individual spots per plot. Localized dry spot (LDS) was determined by estimating the percentage of each plot afflicted with LDS.

Color and quality ratings were taken prior to a nitrogen application (generally four weeks after the last nitrogen application). Both color and quality were rated on a scale of 1 (dead or chlorotic turf) to 9 (excellent turf). Numbers 6 and above were regarded as acceptable turf for a bentgrass putting green.

Analyses of variance were performed on pooled measurements followed by Fischer's protected Least Significant Difference (LSD) if differences were found at $P \geq 0.05$. The LSD was used to compare differences of mean numbers among the different treatments. All data were analyzed using MSTAT [1993] with the exception of standard error estimators for interactions in the split-split-plot design. Interactions were computed by hand with the appropriate degrees of freedom for interactions determined by the procedure introduced by Satterthwaite [Kuehl, 1994

RESULTS & DISCUSSION

Ball Roll Distance

In 1998 and 2000 Stimpmeter measurements were completed three times on the day rolling was applied (Table 17) with six measurements taken in 1999 (Table 18). Root zone had minimal effect on ball roll distance (BRD) during the period as only three of the eleven dates resulted in significant differences. On all three of those dates the native soil green was slower than the other two root zones. However, differences were small and surveys indicate the average golfer cannot detect differences in BRD of 15cm or less [Karcher *et al.*, 2000]. Similar results have been reported by Lodge and Baker [1991].

Rolling resulted in statistically significant BRD on all 11 dates the rolling treatment was applied. Rolled plot BRD ranged from 29-43 cm (11 to 17 %) faster than the non-rolled plots over the three-year period averaging approximately 35 cm (13%) faster overall. These results are similar to previously reported data [Nikolai *et al*, 2001].

Stimpmeter measurements taken the day after a rolling event are reported in Table 19. Four measurements were obtained in 1999 and two in 2000. Once again, root zone had a minimal effect on BRD during the period as only one of the six dates showed significant differences. On that date (3 Aug. 00) the native soil plot was once again significantly slower than the sandier root zones. On all six dates rolling resulted in an average increase of approximately 6% greater than the non-rolled plots the day after the rolling treatment was applied. Nikolai et al. [2001] reported similar results.

Three soil x rolling interactions occurred over the seventeen dates that BRD measurements were taken with no obvious trends (data not shown).

Nitrogen rate also had a significant effect on BRD on all seventeen dates that Stimpmeter measurements were taken. The 146 kg ha^{-1} plots averaged 12cm greater distance than the 293 kg ha^{-1} plots over the three years. The inverse relationship between increasing nitrogen rate and BRD is well documented and has been attributed to the increased growth with the higher N rate [Rieke and McElroy, 1985, Throssell and Duich, 1981]. There was also a trend as the difference in BRD between the two nitrogen rates increased with time with differences of 8cm in 1998, 10cm in 1999, and 19cm in 2000.

Numerous golf course superintendents believe that higher K rates increase BRD due to their understanding that K makes the plant more rigid and upright (verbal communications). Potassium rates in this study resulted in a significant difference on only one occasion (3 Aug, 00) and the difference was minimal (6cm). Some believe the Stimpmeter is not a very accurate tool. Scientists, as well as golf course superintendents, that have utilized the Stimpmeter often rationalize hard to explain measurements as the natural variability that exists with the instrument [Hamilton, 1994]. Data from potassium plots in this study refute the notion the Stimpmeter is not an accurate device as the range of BRD measurements from potassium treatments were 1-6cm with the average magnitude only 3cm. These data suggest the Stimpmeter is a more precise tool than some believe and support the conclusions of Duich [1983] that with a limited amount of experience the Stimpmeter can be used with a high degree of precision.

Table 17. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on Stimpmeter measurements the day rolling treatment were applied, 1998 and 2000.

		Stimpmeter measurements in meters					
Root zone		4 June 98	20 June 98	11 July 98	7 June 00	19 June 00	17 July 00
80:20		2.89a	2.70	3.31	2.84	2.60	2.77
80:10:10		2.87a	2.73	3.28	2.95	2.73	2.85
Native		2.79b	2.69	3.23	2.93	2.67	2.80
Significance		*	NS	NS	NS	NS	NS
Rolling							
Rolled		3.06	2.92	3.46	3.10	2.86	2.98
Not Rolled		2.64	2.49	3.08	2.71	2.47	2.64
Significance		***	***	***	***	***	***
Annual N rate							
293 kg ha^{-1}		2.81	2.81	3.25	2.81	2.57	2.72
146 kg ha^{-1}		2.89	2.93	3.29	3.01	2.76	2.90
Significance		***	NS	NS	***	***	***
Annual K rate							
0 kg ha^{-1}		2.84	2.73	3.28	2.91	2.68	2.81
195 kg ha^{-1}		2.87	2.68	3.26	2.91	2.67	2.81
390 kg ha^{-1}		2.83	2.71	3.28	2.90	2.64	2.80
Significance		NS	NS	NS	NS	NS	NS
Source	df	Mean square					
Replication	2	0.007	0.195	0.087*	0.645*	0.028	0.051
Root zone (S)	2	0.100*	0.020	0.057	0.117	0.167	0.065
Error	4	0.014	0.034	0.012	0.091	0.083	0.014
Rolling (R)	1	4.703***	5.004***	3.882	4.123***	4.183***	3.219***
SR	2	0.046	0.013	0.200	0.004	0.050	0.055*
Error	6	0.021	0.118	0.123	0.042	0.012	0.008
Nitrogen (N)	1	0.204***	0.037	0.046	1.086***	0.969***	0.835***
SN	2	0.006	0.040	0.035	0.034	0.011	0.021*
RN	1	0.005	0.013	0.005	0.095**	0.036	0.007
SRN	2	0.012	0.007	0.006	0.000	0.005	0.005
Potassium (K)	2	0.017	0.023	0.006	0.002	0.017	0.001
SK	4	0.023	0.001	0.017	0.017	0.030	0.015
RK	2	0.001	0.032	0.026	0.006	0.009	0.010
SRK	4	0.003	0.048	0.004	0.005	0.015	0.007
NK	2	0.018	0.045	0.004	0.012	0.004	0.008
SNK	4	0.033	0.018	0.027	0.003	0.023	0.002
RNK	2	0.001	0.016	0.024	0.012	0.019	0.002
SNRK	4	0.012	0.003	0.019	0.006	0.014	0.011
Error	60	0.017	0.020	0.017	0.013	0.013	0.007

*, **, *** Significant at the 0.05 0.01, and 0.001 probability levels, respectively.

Table 18. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on Stimpmeter measurements the day rolling treatment were applied, 1999.

		Stimpmeter measurements in meters				
Root zone		5 Aug.	9 Aug.	11 Aug.	16 Aug.	25 Aug.
80:20		2.65a	2.89	2.85	2.83	2.60a
80:10:10		2.66a	2.94	2.90	2.90	2.65a
Native		2.59b	2.80	2.79	2.87	2.42b
Significance		*	NS	NS	NS	*
Rolling						
Rolled		2.78	3.03	3.02	3.01	2.71
Not Rolled		2.49	2.72	2.67	2.72	2.41
Significance		***	***	***	**	***
Annual N rate						
293 kg ha^{-1}		2.58	2.84	2.79	2.82	2.52
146 kg ha^{-1}		2.69	2.92	2.90	2.92	2.60
Significance		***	***	***	***	***
Annual K rate						
0 kg ha^{-1}		2.62	2.86	2.86	2.90	2.55
195 kg ha^{-1}		2.64	2.88	2.84	2.84	2.55
390 kg ha^{-1}		2.64	2.89	2.85	2.86	2.58
Significance		NS	NS	NS	NS	NS
Source	df	Mean square				
Replication	2	0.019	0.105	0.025	0.016	0.204
Root zone (S)	2	0.058*	0.171	0.097	0.039	0.522*
Error	4	0.006	0.027	0.027	0.051	0.063
Rolling (R)	1	2.211***	2.593***	3.371***	2.282**	2.376***
SR	2	0.013	0.060	0.030	0.017	0.158
Error	6	0.026	0.013	0.010	0.084	0.070
Nitrogen (N)	1	0.320***	0.171***	0.324***	0.269***	0.150***
SN	2	0.008	0.016	0.007	0.014	0.015
RN	1	0.019	0.013	0.002	0.008	0.020
SRN	2	0.004	0.017	0.007	0.003	0.015
Potassium (K)	2	0.014	0.008	0.003	0.026	0.007
SK	4	0.034	0.012	0.003	0.028	0.006
RK	2	0.023	0.000	0.000	0.037	0.007
SRK	4	0.005	0.011	0.008	0.032	0.021
NK	2	0.002	0.025	0.025	0.043	0.039
SNK	4	0.020	0.020	0.012	0.015	0.009
RNK	2	0.020	0.005	0.001	0.010	0.004
SNRK	4	0.020	0.007	0.006	0.010	0.017
Error	60	0.014	0.010	0.013	0.021	0.013

*, **, *** Significant at the 0.05 0.01, and 0.001 probability levels, respectively.

Table 19. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on Stimpmeter measurements the day after rolling, 1999 and 2000.

		Stimpmeter measurements meters					
Root zone		6 Aug. 99	12 Aug. 99†	17 Aug 99	26 Aug 99	6 June 00	3 Aug 00
80:20		2.75	2.61	2.98	2.74	2.81	2.52a
80:10:10		2.75	5.71	2.98	2.74	2.87	2.50a
Native		2.67	2.60	2.99	2.59	2.82	2.41b
Significance		NS	NS	NS	NS	NS	*
Rolling							
Rolled		2.83	2.71	3.05	2.93	2.96	2.52
Not Rolled		2.62	2.60	2.92	2.66	2.71	2.44
Significance		***	*	***	*	***	*
Annual N rate							
293 kg ha^{-1}		2.68	2.61	2.92	2.65	2.74	2.37
146 kg ha^{-1}		2.76	2.71	3.05	2.74	2.92	2.58
Significance		***	***	***	***	***	***
Annual K rate							
0 kg ha^{-1}		2.71	2.68	2.97	2.70	2.84	2.51a
195 kg ha^{-1}		2.75	2.63	2.99	2.69	2.84	2.45b
390 kg ha^{-1}		2.71	2.66	2.99	2.69	2.82	2.47b
Significance		NS	NS	NS	NS	NS	*
Source	df	Mean square					
Replication	2	0.025	0.056	0.162*	0.091	0.029	0.145*
Root zone (S)	2	0.075	0.096	0.003	0.273	0.036	0.133*
Error	4	0.018	0.034	0.021	0.052	0.089	0.013
Rolling (R)	1	1.190***	0.324	0.428***	0.138*	1.658***	0.180*
SR	2	0.019	0.059	0.193**	0.041	0.076*	0.019
Error	6	0.007	0.034	0.011	0.012	0.015	0.024
Nitrogen (N)	1	0.183***	0.285***	0.459***	0.194***	0.902***	1.171***
SN	2	0.020	0.009	0.001	0.003	0.063*	0.033*
RN	1	0.001	0.022	0.011	0.001	0.010	0.000
SRN	2	0.002	0.003	0.010	0.004	0.001	0.020
Potassium (K)	2	0.017	0.025	0.003	0.001	0.005	0.035*
SK	4	0.011	0.004	0.020	0.009	0.014	0.015
RK	2	0.001	0.015	0.015	0.003	0.000	0.003
SRK	4	0.010	0.018	0.023	0.014	0.001	0.004
NK	2	0.017	0.016	0.004	0.006	0.000	0.004
SNK	4	0.005	0.006	0.022	0.009	0.007	0.011
RNK	2	0.009	0.010	0.002	0.009	0.021	0.003
SNRK	4	0.014	0.009	0.012	0.010	0.024	0.019
Error	60	0.011	0.009	0.014	0.010	0.016	0.008

*, **, *** Significant at the 0.05 0.01, and 0.001 probability levels, respectively.

† Rained after rolling and after BRD measurements were made on one replication.

Disease Observations

Sclerotinia homoeocarpa (dollar spot) activity data was collected on twelve dates from 1997-2000 (Tables 20 and 21). On five dates root zone resulted in significant differences with the native soil root zone consistently having less dollar spot than the 80:20 root zone and the 80:10:10 mix continuously resulted in an average number of dollar spots between the 80:20 and native soil root zones. On three occasions the 80:10:10 root zone resulted in significantly less dollar spot than the 80:20 root zone. Lightweight rolling resulted in pooled data with significantly less dollar spot than the non-rolled plots on all dates. These data strengthens earlier observations reported by Nikolai *et al*. [2001] since dollar spot severity was reduced on rolled plots with every dollar spot outbreak over the four-year period.

A conclusive answer to why lightweight rolling three times per week reduces dollar spot severity is elusive. For conjecture, Williams and Powell [1995] noted that guttation droplets escape from wound exudates and these droplets are rich in nutrients that pathogens may use during hyphal growth. Release of these exudates may be exacerbated in the early dawn hour due to a combination of a fresh wound being produced by mowing and that turgor pressure may be high at this time. Rolling, following an early morning mowing, may remove inoculum with excess clippings that failed to be caught in the mower bucket and it may also disperse concentrated guttation water, thus reducing disease severity. However, a dew removal dollar spot study performed by Williams and Powell [1995] suggests it is unlikely that dew and guttation removal would account for reductions of the magnitude observed on the research plots.

Another possible reason rolling reduced dollar spot includes the possibility that the water holding capacity of the root zone may be increased near the surface layer. This would be relevant because Couch and Bloom found low soil moisture to be important in the development of dollar spot and Howard and Smith reported more dollar spot in seasons with less rainfall [Vargas, 1994]. Therefore, if rolling does increase the water holding capacity of the soil it may reduce dollar spot severity. A final theory for reduced severity of dollar spot is rolling may increase phytoalexin production in the plant. Resistance to disease can be increased by altering plant response to parasitic attack through the synthesis of phytoalexins [Marschner, 1995]. Phytoalexins are antimicrobial low-molecular-weight secondary metabolites that are induced to accumulate as a defense response within the plant [Hammerschmidt, 1999]. It is possible that rolling may stress the plant enough to activate phytoalexin accumulation.

Nitrogen rate effect on dollar spot was significant on all dates evaluated. However, on eight dates the higher rate of nitrogen had less dollar spot and on the other four the higher rate resulted in more dollar spot. Vargas [1994] wrote, "According to one school of thought, the number of infections will be greater at high nitrogen levels but the damage will be less severe than if nitrogen levels are low, because although fewer spots appear in the latter case, they tend to be larger and the damage more severe." Following this "school of thought" it stands to reason the number of days after a nitrogen application (as well as nitrogen source and time of year) could be of consequence on the severity of dollar spot infections. Review of dates nitrogen was applied revealed that on the four dates that the higher rate of nitrogen resulted in more dollar spot infections the average amount of days after treatment was 32. For the eight dates that resulted in the higher rate of nitrogen having fewer dollar spot infections the average days after nitrogen application was 14. This supports the theory that during periods of severe dollar spot infection nitrogen levels must be maintained and that a light frequent method of application may be the best form of managing the disease [Vargas, 1994].

It has been reported that maintaining high potassium fertility during periods of dollar spot activity will help control the disease [Smiley, 1983]. However, at no time were significant dollar spot counts obtained regarding the three potassium rates in the study.

A root zone x rolling x nitrogen interaction occurred on six of the twelve dates that dollar spot observations were made (Figures 2-8). Root zone apparently had the biggest impact on the amount of dollar spot infestation with an inverse relationship between the amount of fines and the occurrence of the disease symptoms. In the 80:20 and 80:10:10 root zones, lightweight rolling reduced the amount of dollar spot, most notably at the lower nitrogen rate. The effect of nitrogen rate on dollar spot was variable and as previously stated, apparently had to do with the amount of time that passed after nitrogen was applied.

Color and Quality Ratings

Color and quality ratings were taken periodically from 1998-2000. Both were rated on a scale of 1-9 with 9 signifying excellent, 6 and above acceptable, and 1 equaling chlorotic or dead turf. Color ratings are reported in Tables 22-24. On the 13 dates that color ratings were taken only two were significant in regards to root zone. On those two dates the 80:20 root zone had better color than the 80:10:10 mix with no significance between the 80:20 and native soil root zones. Root zone x nitrogen interactions occurred on 5 dates over the three-year period (Table 27) but no trends resulted from color in the interactions even at the lower nitrogen rate. This indicates that the 146 kg ha^{-1} rate was adequate for turfgrass color even in the 80:20 root zone.

Table 20. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on dollar spot, 1997- Aug. 1998.

		No. of dollar spot m^{-2}					
		1997			1998		
Root zone		24 June	23 July	20 Aug.	16 June	11 July	11 Aug.
80:20		11.69	20.25a	20.46a	20.08a	44.57a	23.66
80:10:10		9.81	13.60a	9.46ab	4.53b	11.93b	7.35
Native		2.16	2.15b	0.49b	0.50b	1.17b	0.55
Significance		NS	*	*	**	**	NS
Rolling							
Rolled		3.28	5.24	5.70	4.75	11.95	7.34
Not Rolled		12.49	18.74	14.57	12.00	26.49	13.70
Significance		*	**	*	*	*	*
Annual N rate							
293 kg ha^{-1}		9.70	13.64	10.96	7.33	16.73	9.30
146 kg ha^{-1}		6.07	10.35	9.32	9.42	21.71	11.74
Significance		***	*	*	**	**	*
Annual K rate							
0 kg ha^{-1}		7.91	12.56	9.97	8.43	20.48	11.82
195 kg ha^{-1}		6.29	10.45	9.49	8.43	18.51	9.32
390 kg ha^{-1}		9.45	12.96	10.96	8.26	18.67	10.41
Significance		NS	NS	NS	NS	NS	NS
		Mean square					
Source	df						
Replication	2	526.79	1198.36	1068.81	523.41	1637.06	536.66
Root zone (S)	2	917.85	3017.09*	3601.34*	3848.67**	18386.01**	5080.99
Error	4	250.56	235.76	476.53	176.98	980.96	1013.60
Rolling (R)	1	2291.38*	4915.87**	2122.57*	1420.01*	5709.84*	1090.45*
SR	2	590.09	1032.69	655.20	422.15	1335.78	287.75
Error	6	255.88	423.63	354.90	173.74	845.12	191.14
Nitrogen (N)	1	355.93***	292.09*	72.71*	117.75**	667.99**	161.31*
SN	2	71.91	55.03	48.21*	30.68	444.04**	204.26**
RN	1	245.24**	221.15*	69.48*	4.71	0.09	1.46
SRN	2	14.05	7.24	47.31*	61.19*	24.57	2.12
Potassium (K)	2	89.94	65.42	20.14	0.35	43.11	56.81
SK	4	43.86	72.54	15.52	0.74	77.70	57.67
RK	2	116.24	52.08	36.71	1.43	74.90	21.58
SRK	4	47.70	97.81	30.33	1.46	124.49	9.88
NK	2	39.86	36.57	15.58	9.50	8.28	3.48
SNK	4	12.86	38.85	9.37	7.44	75.17	6.31
RNK	2	24.07	71.66	29.09	6.54	106.12	25.41
SNRK	4	7.82	15.94	8.95	5.93	29.29	33.44
Error	60	30.84	47.96	14.31	15.26	69.31	29.78

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 21. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on dollar spot Sept. 1998, 1999, and 2000.

		No. of dollar spot m^{-2}					
		1998	1999		2000		
Root zone		17 Sep.	10 June	30 June	14 June	14 July	9 Aug.
80:20		25.86	9.97	6.19a	6.04	3.02	10.17
80:10:10		7.92	5.01	2.40b	4.87	2.61	3.19
Native		1.04	0.47	0.43b	2.78	2.62	1.35
Significance		NS	NS	*	NS	NS	NS
Rolling							
Rolled		5.95	1.45	1.07	2.66	1.19	2.63
Not Rolled		17.26	8.85	4.94	6.50	4.30	7.17
Significance		**	*	*	*	**	**
Annual N rate							
293 kg ha^{-1}		16.26	3.94	1.80	3.09	2.19	2.34
146 kg ha^{-1}		6.96	6.36	4.21	6.04	3.30	7.45
Significance		***	***	***	***	**	***
Annual K rate							
0 kg ha^{-1}		11.80	4.89	2.72	4.01	2.63	4.98
195 kg ha^{-1}		11.66	5.32	3.58	4.60	2.95	4.65
390 kg ha^{-1}		11.36	5.25	2.72	5.09	2.62	5.01
Significance		NS	NS	NS	NS	NS	NS
		Mean square					
Source	df						
Replication	2	979.19	122.68	53.41	58.30	35.37	55.57
Root zone (S)	2	5909.47	813.49	307.77**	98.17	2.01	780.64
Error	4	1050.41	155.03	21.36	113.59	48.40	233.19
Rolling (R)	1	3453.78**	1482.01*	405.97*	391.20*	262.53**	555.86**
SR	2	706.69	370.89	125.87	111.92	2.90	174.09
Error	6	228.34	144.03	35.70	45.92	22.50	40.22
Nitrogen (N)	1	2334.08***	157.57***	156.34***	235.30***	33.10**	709.40***
SN	2	779.47***	92.15***	87.61***	116.99***	33.77***	357.06***
RN	1	697.63***	98.78***	122.61***	147.22***	21.73*	173.43***
SRN	2	100.75*	47.74***	70.58***	30.05*	12.65	57.17**
Potassium (K)	2	1.78	2.00	8.90	10.57	1.10	1.84
SK	4	12.20	1.02	6.98	8.18	1.58	6.46
RK	2	17.89	3.31	3.63	17.07	0.55	2.63
SRK	4	4.89	1.25	5.14	4.24	1.99	1.55
NK	2	10.38	2.15	0.86	10.92	1.15	7.19
SNK	4	5.60	2.22	1.56	10.70	1.50	3.21
RNK	2	13.32	1.38	2.96	0.55	0.05	0.29
SNRK	4	16.43	4.97	3.90	1.13	2.91	1.11
Error	60	30.12	5.12	5.60	8.60	4.60	9.78

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

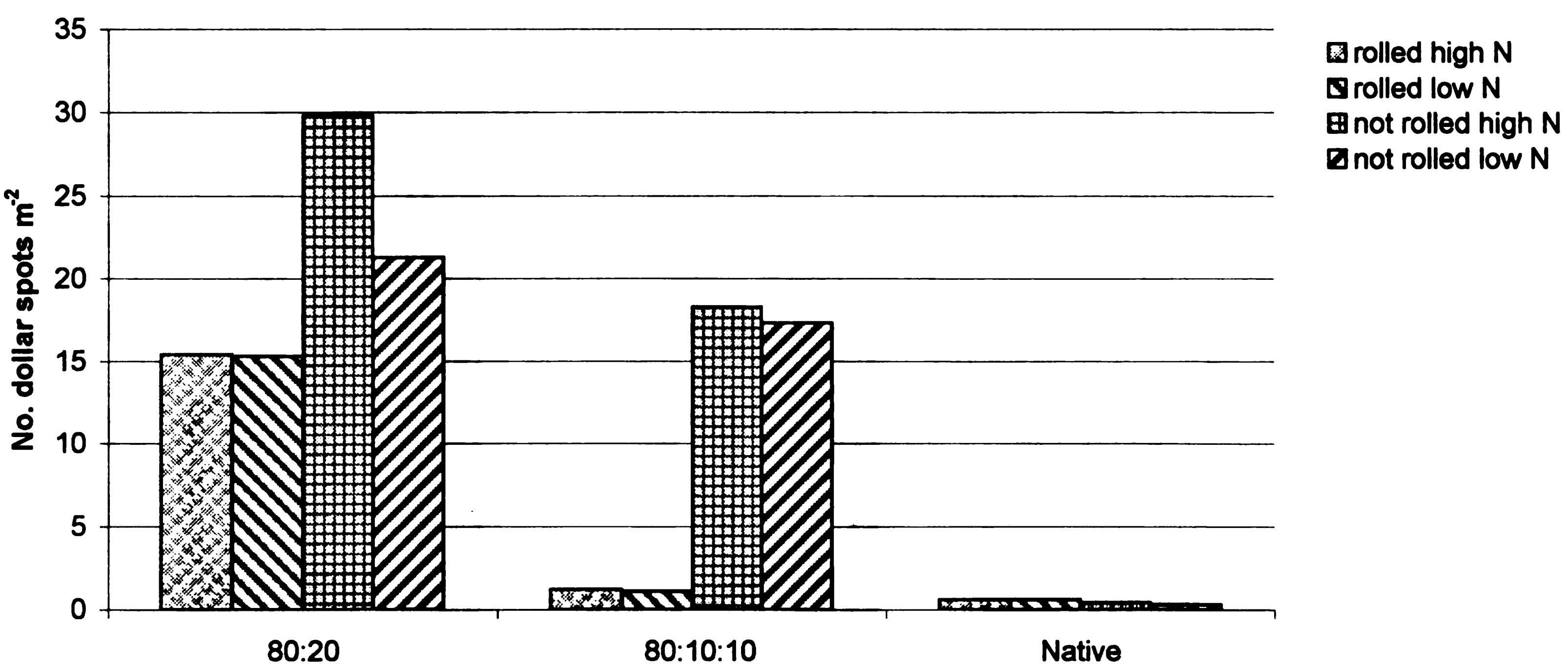

Figure 2. Interaction of root zone, rolling, and nitrogen rate on dollar spot on a creeping bentgrass (*Agrostis palustris* Huds.) green 20 August, 1997 (21 days after a nitrogen treatment).

$LSD_{(0.05)}$ = 3.56 (different levels of nitrogen at the same level of root zone and rolling)
$LSD_{(0.05)}$ = 9.23 (different levels of rolling at the same level of root zone and nitrogen)
$LSD_{(0.05)}$ = 13.83 (different levels of root zone at the same or different levels of rolling and nitrogen)

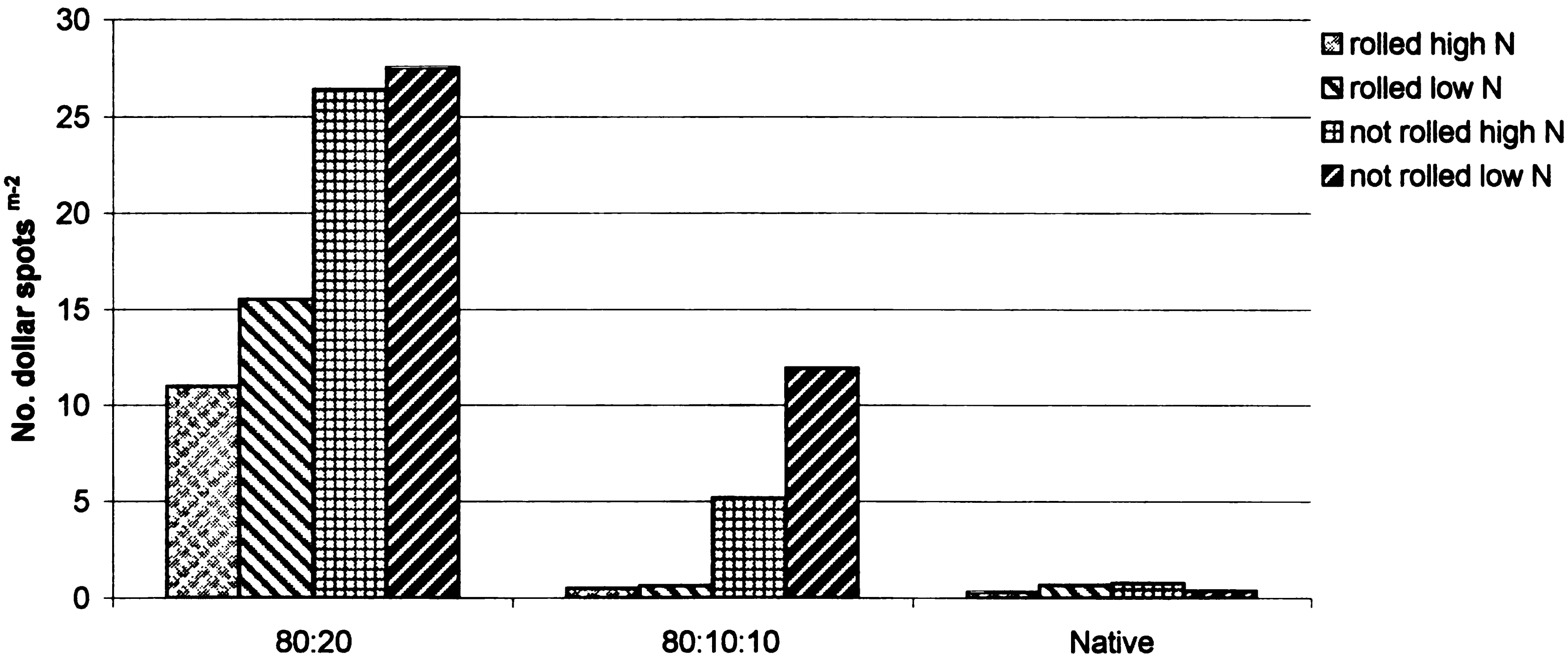

Figure 3. Interaction of root zone, rolling, and nitrogen rate on dollar spot on a creeping bentgrass (*Agrostis palustris* Huds.) green 16 June, 1998 (27 days after a nitrogen treatment).

$LSD_{(0.05)}$ = 3.70(different levels of nitrogen at the same level of root zone and rolling)
$LSD_{(0.05)}$ = 6.74 (different levels of rolling at the same level of root zone and nitrogen)
$LSD_{(0.05)}$ = 9.20 (different levels of root zone at the same or different levels of rolling and nitrogen)

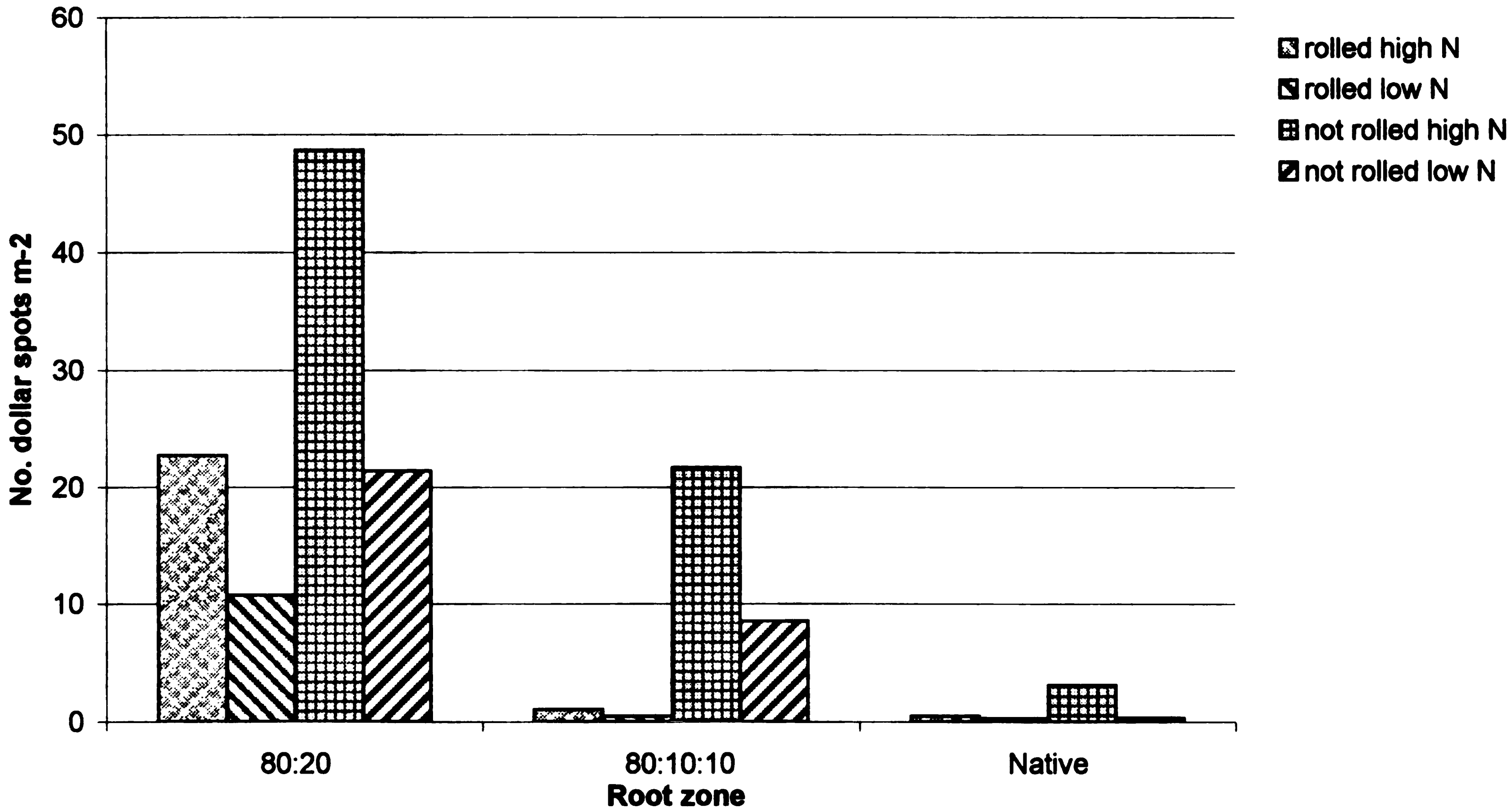

Figure 4. Interaction of root zone, rolling, and nitrogen rate on dollar spot on a creeping bentgrass (*Agrostis palustris* Huds.) green 17 September, 1998 (43 days after a nitrogen treatment).

$LSD_{(0.05)}$ = 5.17 (different levels of nitrogen at the same level of root zone and rolling)
$LSD_{(0.05)}$ = 8.01 (different levels of rolling at the same level of root zone and nitrogen)
$LSD_{(0.05)}$ = 12.20 (different levels of root zone at the same or different levels of rolling and nitrogen)

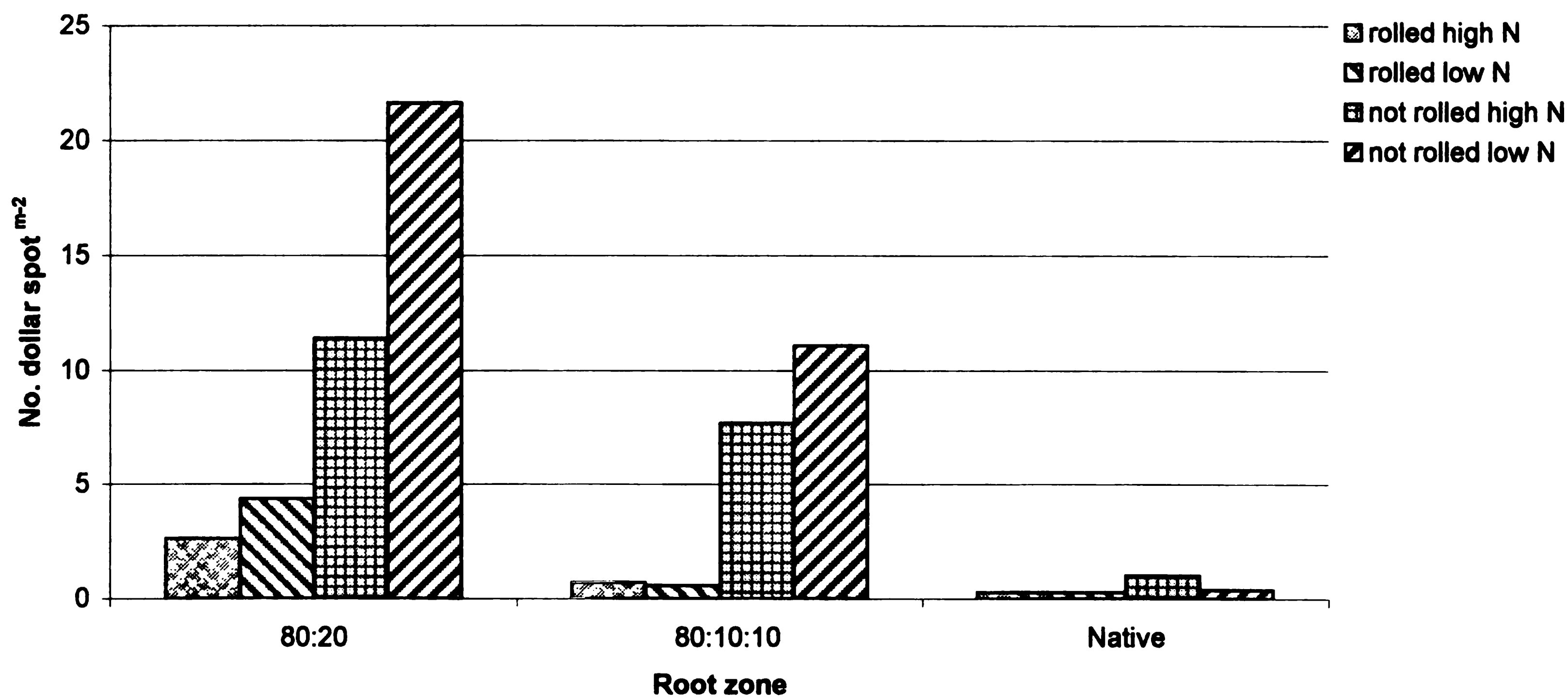

Figure 5. Interaction of root zone, rolling, and nitrogen rate on dollar spot on a creeping bentgrass (*Agrostis palustris* Huds.) green 10 June, 1999 (21 days after a nitrogen treatment).

$LSD_{(0.05)}$ = 2.13 (different levels of nitrogen at the same level of root zone and rolling)
$LSD_{(0.05)}$ = 5.86 (different levels of rolling at the same level of root zone and nitrogen)
$LSD_{(0.05)}$ = 8.29 (different levels of root zone at the same or different levels of rolling and nitrogen)

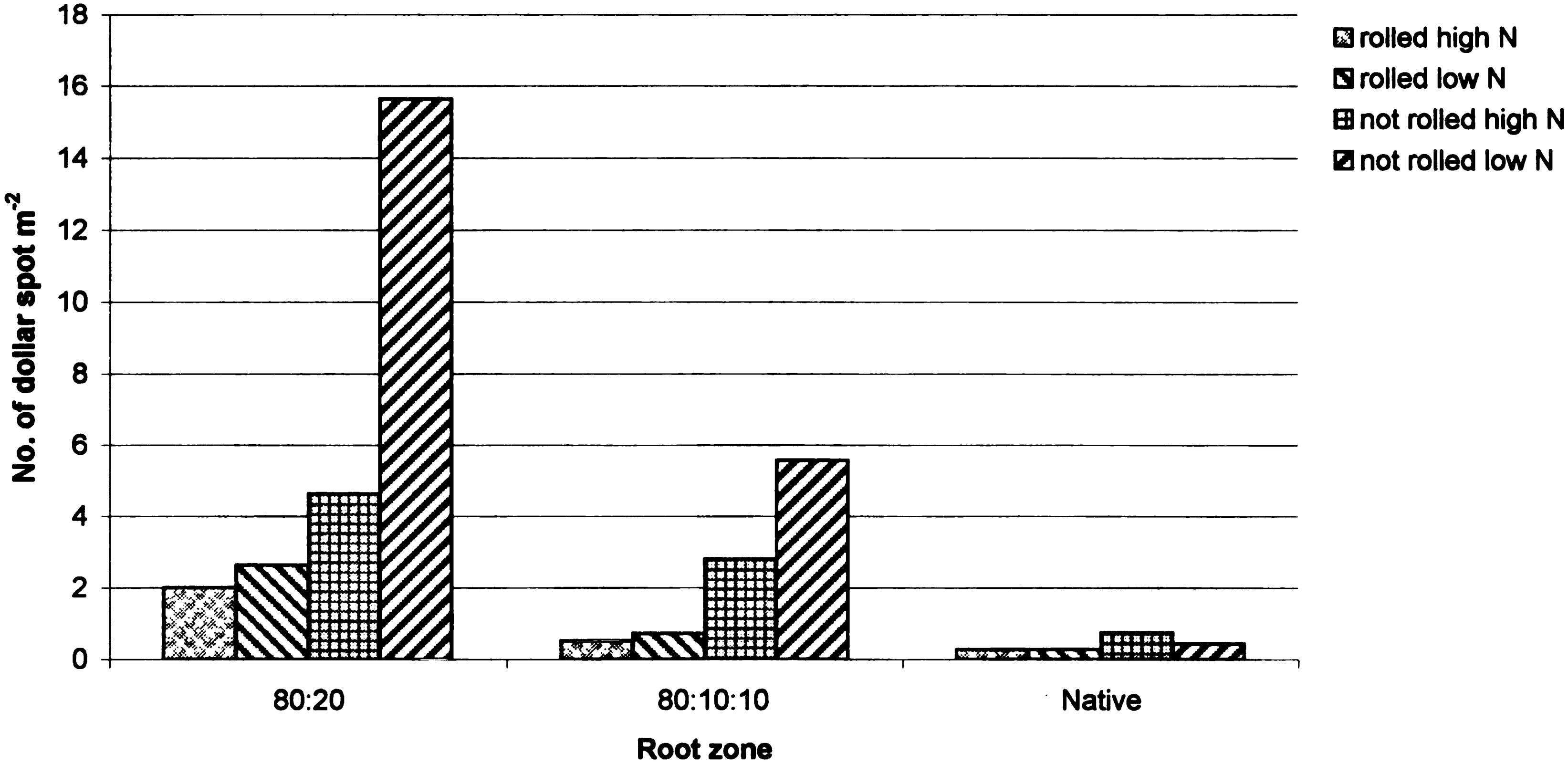

Figure 6. Interaction of root zone, rolling, and nitrogen rate on dollar spot on a creeping bentgrass (*Agrostis palustris* Huds.) green 30 June, 1999 (6 days after a nitrogen treatment).

$LSD_{(0.05)}$ = 2.23 (different levels of nitrogen at the same level of root zone and rolling)

$LSD_{(0.05)}$ = 3.23 (different levels of rolling at the same level of root zone and nitrogen)

$LSD_{(0.05)}$ = 3.89 (different levels of root zone at the same or different levels of rolling and nitrogen)

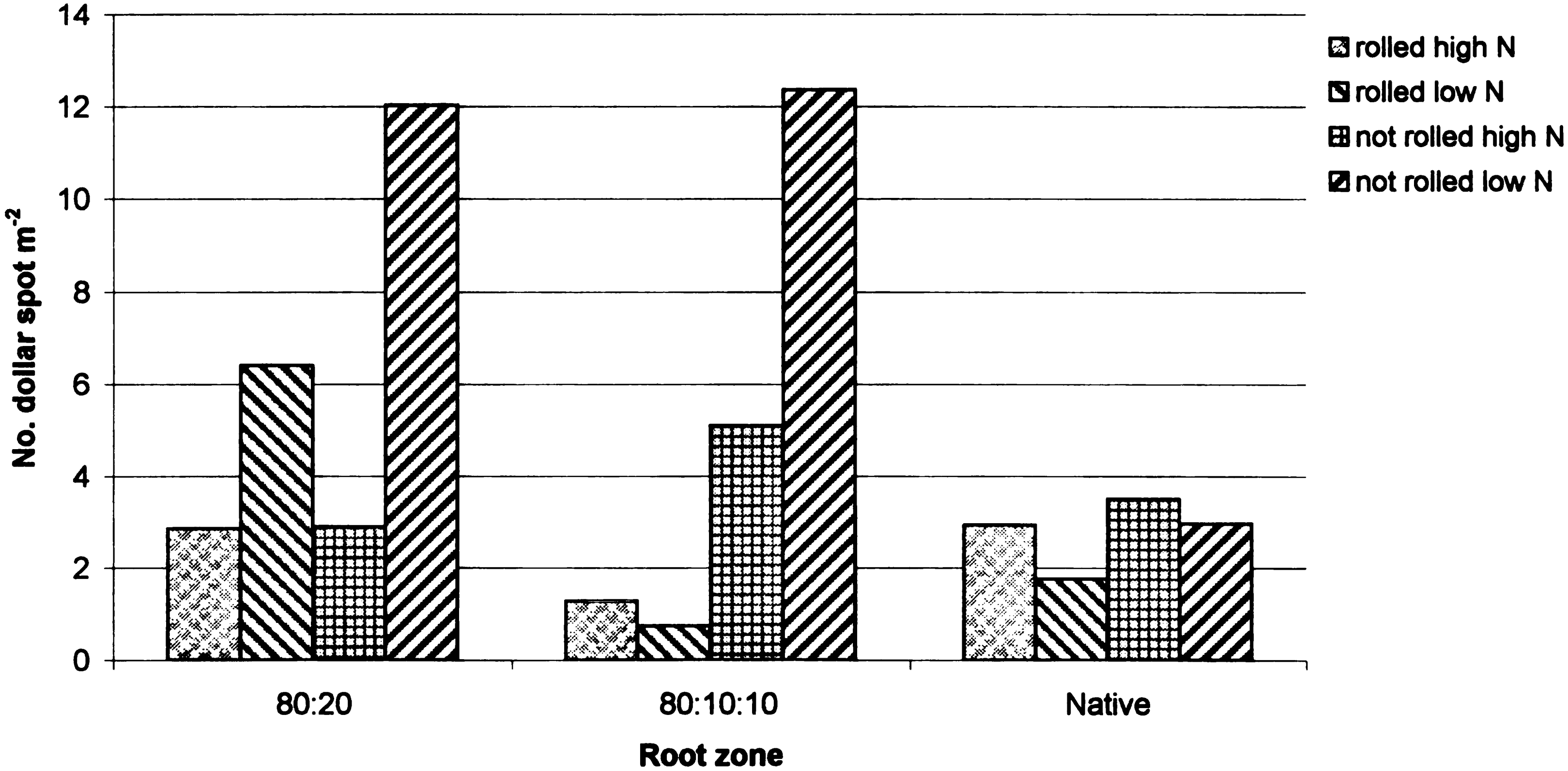

Figure 7. Interaction of root zone, rolling, and nitrogen rate on dollar spot on a creeping bentgrass (*Agrostis palustris* Huds.) green 14 June, 2000 (23 days after a nitrogen treatment).

$LSD_{(0.05)}$ = 2.76 (different levels of nitrogen at the same level of root zone and rolling)
$LSD_{(0.05)}$ = 3.74 (different levels of rolling at the same level of root zone and nitrogen)
$LSD_{(0.05)}$ = 6.26 (different levels of root zone at the same or different levels of rolling and nitrogen)

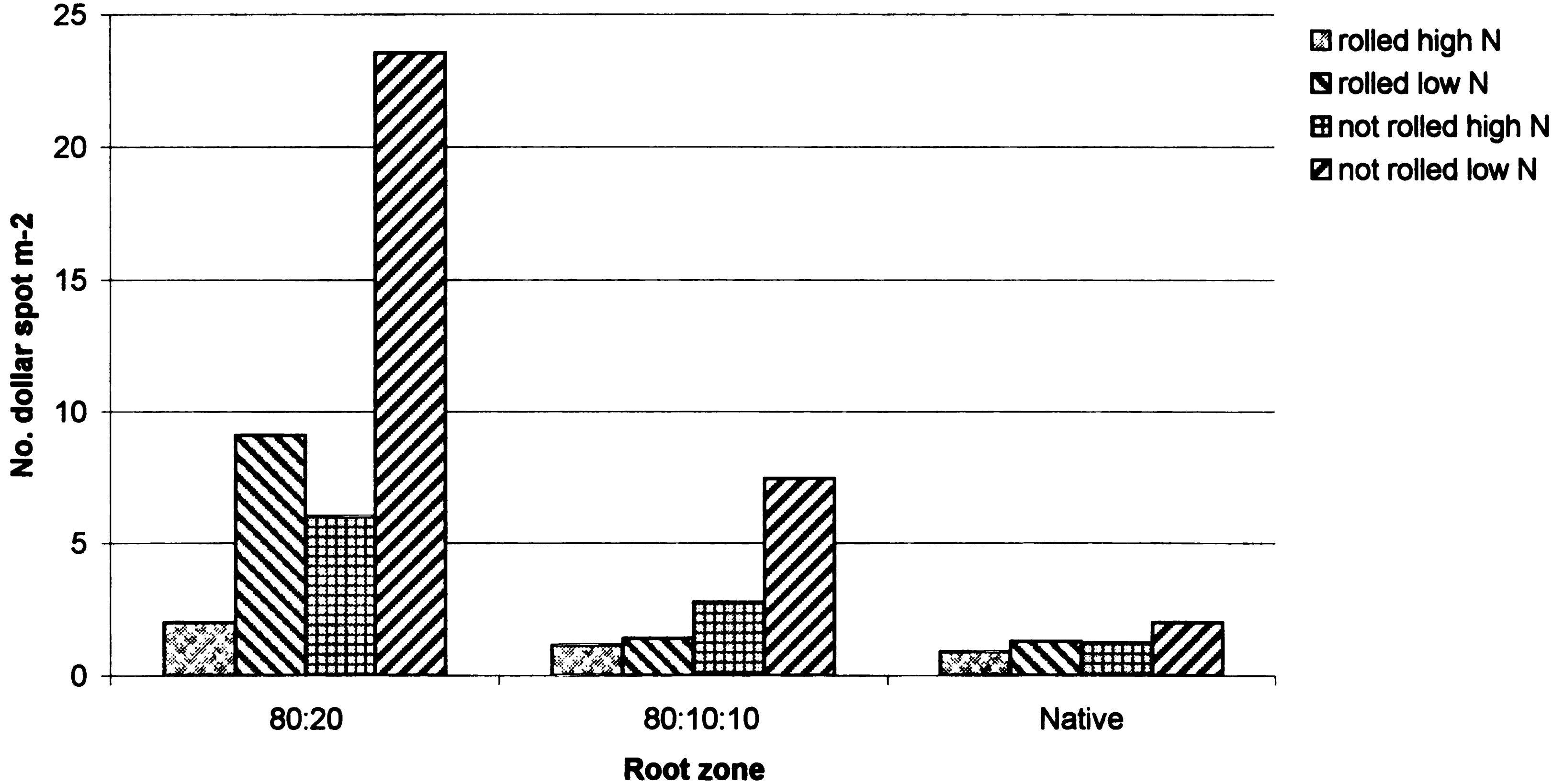

Figure 8. Interaction of root zone, rolling, and nitrogen rate on dollar spot on a creeping bentgrass (*Agrostis palustris* Huds.) green 9 August, 2000 (12 days after a nitrogen treatment).

$LSD_{(0.05)}$ = 2.95 (different levels of nitrogen at the same level of root zone and rolling)
$LSD_{(0.05)}$ = 3.64 (different levels of rolling at the same level of root zone and nitrogen)
$LSD_{(0.05)}$ = 5.70 (different levels of root zone at the same or different levels of rolling and nitrogen)

Table 22. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on color ratings, 1998.

		Color rating (9 = excellent, 6≥ acceptable, 1 = dead)				
Root zone		30 May	13 June	11 July	10 Aug.	10 Oct.
80:20		6.8	7.1	7.5	7.6a	7.2
80:10:10		7.1	7.5	7.2	7.4b	6.5
Native		7.3	7.7	7.6	7.5a	6.8
Significance		NS	NS	NS	**	NS
Rolling						
Rolled		7.3	7.4	7.3	7.5	6.6
Not Rolled		7.1	7.3	7.6	7.6	7.1
Significance		NS	NS	NS	NS	**
Annual N rate						
293 kg ha^{-1}		7.7	7.9	7.7	7.9	7.1
146 kg ha^{-1}		7.0	6.9	7.2	7.2	6.6
Significance		***	***	***	***	***
Annual K rate						
0 kg ha^{-1}		7.2	7.4	7.5	7.6	6.8
195 kg ha^{-1}		7.1	7.4	7.5	7.6	6.8
390 kg ha^{-1}		7.2	7.4	7.4	7.5	6.8
Significance		NS	NS	NS	NS	NS
		Mean square				
Source	df					
Replication	2	0.29	2.70	0.71	0.21*	0.08
Root zone (S)	2	6.36	3.47	1.19	0.71**	3.45
Error	4	1.29	0.83	0.53	0.02	0.81
Rolling (R)	1	0.93	0.28	1.45	0.93	6.65**
SR	2	0.31	0.002	0.50	1.07	5.18**
Error	6	0.45	0.31	0.43	0.33	0.43
Nitrogen (N)	1	25.04***	29.56***	9.19***	15.56***	7.89***
SN	2	0.25*	0.57*	0.21	0.11*	0.16
RN	1	0.75**	1.95***	0.06	0.01	0.16
SRN	2	0.30*	0.24	0.03	0.02	0.11
Potassium (K)	2	0.07	0.03	0.06	0.01	0.01
SK	4	0.08	0.04	0.08	0.01	0.22
RK	2	0.04	0.11	0.02	0.03	0.02
SRK	4	0.04	0.05	0.01	0.01	0.08
NK	2	0.02	0.11	0.01	0.02	0.12
SNK	4	0.05	0.05	0.06	0.02	0.03
RNK	2	0.09	0.03	0.02	0.002	0.04
SNRK	4	0.00	0.08	0.01	0.01	0.08
Error	60	0.07	0.15	0.08	0.03	0.12

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 23. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on color ratings, 1999.

		Color rating (9 = excellent, 6≥ acceptable, 1 = dead)			
Root zone		13 May	10 Aug.	8 Sep.	5 Oct.
80:20		6.2	7.0	7.1	6.7
80:10:10		6.6	6.6	6.8	6.5
Native		6.7	6.6	7.0	6.7
Significance		NS	NS	NS	NS
Rolling					
Rolled		6.5	6.7	7.1	6.6
Not Rolled		6.4	6.8	6.9	6.6
Significance		NS	NS	NS	NS
Annual N rate					
293 kg ha^{-1}		6.8	7.2	7.4	7.1
146 kg ha^{-1}		6.1	6.3	6.5	6.1
Significance		***	***	***	***
Annual K rate					
0 kg ha^{-1}		6.5	6.7	7.0	6.6
195 kg ha^{-1}		6.5	6.7	7.0	6.6
390 kg ha^{-1}		6.5	6.8	7.0	6.6
Significance		NS	NS	NS	NS
		Mean square			
Source	df				
Replication	2	0.45	3.88	1.96	0.26
Root zone (S)	2	2.34	2.53	0.95	0.67
Error	4	0.59	0.97	0.37	0.22
Rolling (R)	1	0.28	0.75	0.93	0.002
SR	2	0.07	0.53	2.15*	0.22
Error	6	0.18	0.50	0.40	0.39
Nitrogen (N)	1	13.72***	18.75***	22.23***	29.56***
SN	2	1.47***	0.25*	0.46**	0.11
RN	1	0.06	0.23	0.01	0.002
SRN	2	0.18	0.17	0.22	0.29*
Potassium (K)	2	0.002	0.02	0.03	0.03
SK	4	0.02	0.01	0.06	0.06
RK	2	0.002	0.02	0.24	0.12
SRK	4	0.04	0.03	0.01	0.07
NK	2	0.002	0.05	0.04	0.45**
SNK	4	0.04	0.01	0.06	0.03
RNK	2	0.002	0.06	0.03	0.04
SNRK	4	0.023	0.11	0.04	0.04
Error	60	0.102	0.07	0.09	0.08

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 24. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on color ratings, 2000.

		Color rating (9 = excellent, 6≥ acceptable, 1 = dead)			
Root zone		22 May	22 May	28 June	3 Aug.
80:20		6.5	6.6	7.2	7.4
80:10:10		6.5	6.2	6.2	7.3
Native		6.5	5.9	6.6	7.4
Significance		NS	NS	*	NS
Rolling					
Rolled		6.5	6.3	6.7	7.3
Not Rolled		6.5	6.2	6.6	7.4
Significance		NS	NS	NS	NS
Annual N rate					
293 kg ha^{-1}		8.0	6.7	7.4	8.0
146 kg ha^{-1}		5.0	5.8	6.0	6.7
Significance		NS	***	***	***
Annual K rate					
0 kg ha^{-1}		6.5	6.2	6.6	7.3
195 kg ha^{-1}		6.5	6.2	6.7	7.3
390 kg ha^{-1}		6.5	6.3	6.7	7.4
Significance		NS	NS	NS	NS
		Mean square			
Source	df				
Replication	2	0.00	2.02	5.44	0.29
Root zone (S)	2	0.00	4.78	8.11*	0.04
Error	4	0.00	1.30	0.76	0.15
Rolling (R)	1	0.00	0.06	0.23	0.08
SR	2	0.00	0.50	0.04	0.11
Error	6	0.00	1.11	1.38	0.05
Nitrogen (N)	1	0.00	20.89***	52.08***	41.56***
SN	2	0.00	0.29	0.33	0.15
RN	1	0.00	0.02	0.45	0.08
SRN	2	0.00	0.34	0.15	0.11
Potassium (K)	2	0.00	0.27	0.11	0.06
SK	4	0.00	0.10	0.22	0.05
RK	2	0.00	0.09	0.04	0.58**
SRK	4	0.00	0.09	0.26	0.07
NK	2	0.00	0.22	0.11	0.01
SNK	4	0.00	0.11	0.28	0.13
RNK	2	0.00	0.02	0.34	0.19
SNRK	4	0.00	0.05	0.15	0.10
Error	60	0.00	0.13	0.24	0.12

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 25. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on quality ratings, 1998.

Root zone		Quality rating (9 = excellent, 6≥ acceptable, 1 = dead) 13 June	11 July	10 Aug.	10 Oct.
80:20		6.5	7.3	7.4b	6.7
80:10:10		7.1	7.1	7.0c	6.1
Native		7.1	7.4	7.6a	6.3
Significance		NS	NS	**	NS
Rolling					
Rolled		7.0	7.2	7.3	6.1
Not Rolled		6.8	7.3	7.4	6.7
Significance		NS	NS	NS	NS
Annual N rate					
293 kg ha^{-1}		7.7	7.6	7.8	6.8
146 kg ha^{-1}		6.2	6.9	6.9	6.0
Significance		***	***	***	***
Annual K rate					
0 kg ha^{-1}		6.8	7.2	7.3	6.4
195 kg ha^{-1}		6.9	7.3	7.3	6.3
390 kg ha^{-1}		7.0	7.2	7.3	6.4
Significance		NS	NS	NS	NS
		Mean square			
Source	df				
Replication	2	7.56	2.96	0.32	0.78
Root zone (S)	2	5.65	0.81	3.54**	3.82
Error	4	4.74	0.50	0.15	1.77
Rolling (R)	1	1.84	0.93	0.28	9.49**
SR	2	0.01	2.38*	1.13	12.45***
Error	6	0.37	0.32	0.56	0.53
Nitrogen (N)	1	59.41***	13.37***	20.02***	16.33***
SN	2	1.31**	0.50*	0.21*	0.05
RN	1	3.38***	0.08	0.02	0.04
SRN	2	0.23	0.05	0.15	0.07
Potassium (K)	2	0.35	0.01	0.002	0.02
SK	4	0.07	0.07	0.06	0.16
RK	2	0.37	0.002	0.15	0.03
SRK	4	0.08	0.04	0.05	0.05
NK	2	0.36	0.04	0.06	0.27
SNK	4	0.22	0.11	0.07	0.10
RNK	2	0.15	0.05	0.05	0.02
SNRK	4	0.26	0.08	0.03	0.12
Error	60	0.19	0.13	0.07	0.14

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 26. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on quality ratings, 1999.

		Quality rating (9 = excellent, 6≥ acceptable, 1 = dead)			
Root zone		13 May	10 Aug.	8 Sep.	5 Oct
80:20		5.8	5.5	6.4	6.4
80:10:10		6.4	5.7	6.2	6.3
Native		6.4	6.5	7.0	6.5
Significance		NS	NS	NS	NS
Rolling					
Rolled		6.3	6.4	6.7	6.5
Not Rolled		6.1	5.4	6.1	6.5
Significance		NS	**	*	NS
Annual N rate					
293 kg ha^{-1}		6.7	6.2	6.9	7.1
146 kg ha^{-1}		5.7	5.6	5.9	5.9
Significance		***	***	***	***
Annual K rate					
0 kg ha^{-1}		6.1	5.9	6.4	6.6
195 kg ha^{-1}		6.1	5.9	6.4	6.5
390 kg ha^{-1}		6.2	6.0	6.4	6.4
Significance		NS	NS	NS	NS
		Mean square			
Source	df				
Replication	2	0.42	1.18	5.09	0.21
Root zone (S)	2	3.88	11.25	2.42	0.96
Error	4	1.22	7.10	0.97	0.17
Rolling (R)	1	0.84	29.04**	12.00	0.15
SR	2	0.46	2.02	0.46*	0.21
Error	6	0.28	2.23	1.26	0.59
Nitrogen (N)	1	26.50***	10.70***	26.01***	41.56***
SN	2	1.47***	0.17	0.46*	0.11
RN	1	0.11	0.93*	0.00	0.01
SRN	2	0.63*	0.18	0.46*	0.10
Potassium (K)	2	0.13	0.23	0.01	0.11
SK	4	0.10	0.10	0.07	0.06
RK	2	0.11	0.12	0.09	0.29*
SRK	4	0.11	0.06	0.11	0.10
NK	2	0.02	0.01	0.21	0.45**
SNK	4	0.20	0.04	0.11	0.002
RNK	2	0.18	0.01	0.01	0.01
SNRK	4	0.18	0.12	0.09	0.04
Error	60	0.15	0.15	0.13	0.08

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 27. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on quality ratings, 2000.

		Quality rating (9 = excellent, 6≥ acceptable, 1 = dead)			
Root zone		14 April	22 May	28 June	3 Aug.
80:20		6.5	6.5	7.2a	7.4
80:10:10		6.5	6.0	6.2b	7.3
Native		6.5	5.7	6.6ab	7.4
Significance		NS	NS	*	NS
Rolling					
Rolled		6.5	6.1	6.7	7.3
Not Rolled		6.5	6.0	6.6	7.4
Significance		NS	NS	NS	NS
Annual N rate					
293 kg ha^{-1}		8.0	6.6	7.4	8.0
146 kg ha^{-1}		5.0	5.5	6.0	6.7
Significance		NS	***	***	***
Annual K rate					
0 kg ha^{-1}		6.5	6.0	6.6	7.3
195 kg ha^{-1}		6.5	6.0	6.7	7.3
390 kg ha^{-1}		6.5	6.1	6.7	7.4
Significance		NS	NS	NS	NS
		Mean square			
Source	df				
Replication	2	0.00	3.40	5.44	0.29
Root zone (S)	2	0.00	6.79	8.11*	0.04
Error	4	0.00	1.06	0.76	0.15
Rolling (R)	1	0.00	0.45	0.23	0.08
SR	2	0.00	1.23	0.04	0.11
Error	6	0.00	0.92	1.38	0.05
Nitrogen (N)	1	0.00	35.59***	52.08***	41.56***
SN	2	0.00	2.26***	0.33	0.15
RN	1	0.00	0.59	0.45	0.08
SRN	2	0.00	0.73	0.15	0.11
Potassium (K)	2	0.00	0.06	0.11	0.06
SK	4	0.00	0.15	0.22	0.05
RK	2	0.00	0.03	0.04	0.58**
SRK	4	0.00	0.09	0.26	0.07
NK	2	0.00	0.18	0.11	0.01
SNK	4	0.00	0.07	0.28	0.13
RNK	2	0.00	0.02	0.34	0.19
SNRK	4	0.00	0.06	0.15	0.10
Error	60	0.00	0.25	0.24	0.12

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 28. Color ratings as affected by root zone and nitrogen rate† (9 = excellent, 6≥ acceptable, 1 = dead).

	Nitrogen rate in kg ha^{-1} year^{-1}									
	13 June 1998		10 Aug. 1998		13 May 1999		10 Aug. 1999		8 Sep. 1999	
Root zone	293 kg ha^{-1}	146 kg ha^{-1}	293 kg ha^{-1}	146 kg ha^{-1}	293 kg ha^{-1}	146 kg ha^{-1}	293 kg ha^{-1}	146 kg ha^{-1}	293 kg ha^{-1}	146 kg ha^{-1}
80:20	7.7	6.4	8.0	7.2	6.8	5.6	7.5	6.6	7.5	6.7
80:10:10	8.0	6.9	7.8	7.0	6.9	6.2	7.1	6.1	7.4	6.2
Native	8.1	7.3	8.0	7.4	6.9	6.5	6.9	6.2	7.4	6.6
LSD $_{(0.05)}$‡	0.25		0.12		0.22		0.17		0.20	
LSD $_{(0.05)}$§	0.46		0.11		0.39		0.48		0.32	

† Nitrogen rates shown are annual rates which were applied in six equal increments from May through November.

‡ Between nitrogen means at same root zone.

§ Between root zone at the same or different level of nitrogen.

Table 29. Quality ratings as affected by root zone and nitrogen rate† (9 = excellent, 6≥ acceptable, 1 = dead).

	13 June 1998		11 July 1998		10 Aug. 1998	
Root zone	293 kg ha^{-1}	146 kg ha^{-1}	293 kg ha^{-1}	146 kg ha^{-1}	293 kg ha^{-1}	146 kg ha^{-1}
80:20	7.4	5.5	7.8	6.8	7.8	6.9
80:10:10	7.8	6.5	7.4	6.8	7.5	6.5
Native	7.7	6.6	7.6	7.1	8.0	7.3
LSD $_{(0.05)}$‡	0.29		0.24		0.18	
LSD $_{(0.05)}$§	1.05		0.37		0.22	

† Nitrogen rates shown are annual rates which were applied in six equal increments from May through November.

‡ Between nitrogen means at same root zone.

§ Between root zone at the same or different level of nitrogen.

Rolling had little impact on turfgrass color with only one date resulting in a significant difference (Table 22). On that date non-rolled plots had better color. On two occasions a soil x rolling x nitrogen interaction occurred in regard to color. On both dates the rolled plots, at both nitrogen rates, received higher color ratings (data not shown).

Not surprisingly, the higher nitrogen rate resulted in a better color rating on all dates. Potassium had no significant effect on color. There was a nitrogen x potassium interaction on 5 October 1999. On that date the highest nitrogen rate at the highest potassium rate had significantly lower color (data not shown).

Quality ratings take into account turfgrass color and density and are presented in Tables 25-27. Only two of the twelve dates resulted in significant differences with the 80:20 having significantly better quality than the 80:10:10 on both dates. Rolling also resulted in significant differences on two dates and on both of those dates the rolled plots had better quality than the non-rolled plots. On all twelve dates the higher rate of nitrogen had significantly better quality while potassium rates had no impact on turfgrass quality.

Quality rating interactions affected by root zone and nitrogen rate are in Table 29. Quality ratings were affected by dollar spot severity and therefore the native soil green tended to have better quality.

Miscellaneous Data

During 1998 broadleaf weeds, *Taraxacum officinale* and *Plantago major*, infested the plots. On 2 October counts on these broadleaf weeds were made (Table 30). The higher nitrogen rate resulted in significantly less weeds than the lower nitrogen rate. This would be expected since increased turf density, attributed to higher N rates, is known to reduce weed encroachment. Rolled plots also resulted in significantly fewer broadleaf weeds. Root zone and potassium treatments had no effect on broadleaf weed counts.

Following a rain event in August 2000, irrigation was turned-off to allow the plots to dry for the development of localized dry spot (LDS). Similar attempts were made in previous years to collect LDS data but no significant data resulted. In Table 30 significant LDS data is presented. On 29 August both the rolled plots and lower N fertility plots resulted in less LDS. In September no significant data resulted due to rolling, however, the lower nitrogen rate maintained less LDS than the higher rate. The rolling x nitrogen interaction regarding LDS is presented in Table 31. Plots with the higher nitrogen rate that were not rolled averaged the greatest amount of LDS. However, there were no significant differences between nitrogen rates on rolled plots. Potassium rate had no effect on LDS. A root zone x nitrogen rate interaction occurred in September (Table 32). On that date the native soil green at the high rate of N had the most localized dry spot. The 80:10:10 mix had significantly less localized dry spot than the other two-root zones at both nitrogen rates. The practice of sand topdressing most likely had an effect on the LDS among the root zones. Since the majority of roots are in the STL, (Table 54 Chapter III) and the native root zone would be expected to have more micropores, it is possible the fine-textured soil below the coarse-textured STL would draw water away fro the STL into the native root zone. The STL would have less of an impact on the other two root zones, thus the sandy root zone with more fines (80:10:10) would conceivably have less LDS than the 80:20 root zone.

Table 30. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on broadleaf weeds and localized dry spot.

		Broadleaf weeds m^{-2}	% localized dry spot m^{-2}	
		2 October 1998	29 August 2000	7 September 2000
Root zone				
80:20		0.925	1.17	1.42
80:10:10		0.769	0.42	0.30
Native		0.890	1.95	2.05
Significance		NS	NS	NS
Rolling				
Rolled		0.664	0.69	0.99
Not Rolled		1.058	1.67	1.52
Significance		***	*	NS
Annual N rate				
293 kg ha^{-1}		0.465	1.44	1.62
146 kg ha^{-1}		1.258	0.92	0.89
Significance		***	**	***
Annual K rate				
0 kg ha^{-1}		0.755	1.06	1.20
195 kg ha^{-1}		0.925	1.20	1.19
390 kg ha^{-1}		0.904	1.28	1.38
Significance		NS	NS	NS
		Mean square		
Source	df			
Replication	2	1.502	19.07	47.09
Root zone (S)	2	0.243	21.09	28.31
Error	4	0.357	5.10	17.13
Rolling (R)	1	4.190***	25.56*	7.77
SR	2	0.497	5.07	4.36
Error	6	0.120	2.61	8.06
Nitrogen (N)	1	16.962***	7.49**	14.61***
SN	2	0.121	2.61	3.88*
RN	1	0.584	9.81**	1.12
SRN	2	0.132	1.82	0.16
Potassium (K)	2	0.312	0.45	0.43
SK	4	0.010	1.42	0.24
RK	2	0.059	0.36	1.09
SRK	4	0.217	0.67	2.09
NK	2	0.001	0.91	0.24
SNK	4	0.043	0.92	0.56
RNK	2	0.329	0.18	0.87
SNRK	4	0.251	0.24	0.62
Error	60	0.182	1.01	0.90

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 31. Percentage of localized dry spot m^{-2} as affected by rolling† and nitrogen rate‡.

Root zone	29 August 2000	
	293 kg ha^{-1}	146 kg ha^{-1}
Rolled	0.66	0.73
Not Rolled	2.23	1.10
$LSD_{(0.05)}$ §	0.55	
$LSD_{(0.05)}$ ¶	0.73	

† Rolling was applied three times per week from May till September with an Olathe lightweight green roller.

‡ Nitrogen rates shown are annual rates which were applied in six equal increments from May through November .

§ Between nitrogen treatments at same rolling treatment.

¶ Between rolling treatments at the same or different level of nitrogen.

Table 32. Percentage of localized dry spot m^{-2} as affected by root zone and nitrogen rate†.

Root zone	7 September 2000	
	293 kg ha^{-1}	146 kg ha^{-1}
80:20	1.81	1.02
80:10:10	0.34	0.27
Native	2.73	1.35
$LSD_{(0.05)}$ ‡	0.63	
$LSD_{(0.05)}$ §	1.41	

† Nitrogen rates shown are annual rates which were applied in six equal increments from May through November.

‡ Between nitrogen means at same root zone.

§ Between root zone at the same or different level of nitrogen

Table 33. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on bird beak holes, 1999-2000.

		No. of bird beak holes m^{-2}	
		19 July 1999	14 August 2000
Root zone			
80:20		14.075	1.146
80:10:10		10.508	0.961
Native		7.404	0.748
Significance		NS	NS
Rolling			
Rolled		6.236	0.576
Not Rolled		15.088	1.324
Significance		*	NS
Annual N rate			
293 kg ha^{-1}		12.492	1.087
146 kg ha^{-1}		8.833	0.816
Significance		***	*
Annual K rate			
0 kg ha^{-1}		9.874	0.961
195 kg ha^{-1}		11.590	0.990
390 kg ha^{-1}		10.522	0.904
Significance		NS	NS
		Mean square	
Source	df		
Replication	2	685.054	7.777
Root zone (S)	2	401.128	1.433
Error	4	176.160	2.123
Rolling (R)	1	2115.456*	14.992
SR	2	149.848	4.250
Error	6	219.865	2.755
Nitrogen (N)	1	361.539***	1.976*
SN	2	80.806***	0.380
RN	1	110.892**	0.015
SRN	2	16.032	0.440
Potassium (K)	2	27.023	0.068
SK	4	17.635	0.210
RK	2	17.426	0.119
SRK	4	9.182	0.183
NK	2	4.009	0.285
SNK	4	3.129	0.319
RNK	2	15.630	0.236
SNRK	4	21.679	0.196
Error	60	11.029	0.485

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Bird activity was high on the site coinciding with numerous *Agrotis ipsilon* (black cutworm) observed on the plots in July of 1999 and August of 2000. There were significantly less bird beak intrusions on greens that were rolled three times per week in July 1999 (Table 33). Reductions of 56% have previously been reported on rolled plots [Nikolai *et al.*, 2001]. In 1999 there were 59% less bird beak intrusions on the rolled greens and in 2000, 56% fewer. Potter [1998] reported that black cutworm moths lay nearly all their eggs on the tips of leaf blades and that many eggs survive passage through the mower blades and will hatch later. Considering debris (excess clippings that miss the bucket) adhered to the rollers and was transported off-site, it is conceivable that rolling could have decreased the amount of cutworms per green by removing the eggs with the excess debris.

The higher rate of nitrogen had significantly more bird beak instructions in both years. The rolling by nitrogen interaction is presented in Table 34. Rolling significantly decreased the amount of bird beak intrusions at both rates of nitrogen (60% less at 293 kg ha^{-1} and 56% less at 146 kg ha^{-1}) and there was no significant effect of nitrogen on rolled plots. The interaction of root zone by nitrogen rate is presented in Table 35. On the sandier soil nitrogen had more of an impact on the bird beak holes with no significant difference on the native soil plots. Furthermore, the 80:20 had the most bird beak intrusions. This data is consistent with previous findings [Nikolai *et al.* 2001].

Table 34. Number of bird beak holes m^{-2} as affected by rolling[†] and nitrogen rate[‡].

Root zone	19 July 1999	
	293 kg ha^{-1}	146 kg ha^{-1}
Rolled	7.05	5.42
Not Rolled	17.93	12.24
LSD $_{(0.05)}$[§]	1.81	
LSD $_{(0.05)}$[¶]	5.85	

† Rolling was applied three times per week from May till September with an Olathe lightweight green roller.

‡ Nitrogen rates shown are annual rates which were applied in six equal increments from May through November .

§ Between nitrogen treatments at same rolling treatment.

¶ Between rolling treatments at the same or different level of nitrogen.

Table 35. Number of bird beak holes m^{-2} as affected by root zone and nitrogen rate[†].

Root zone	19 July 1999	
	293 kg ha^{-1}	146 kg ha^{-1}
80:20	17.31	10.83
80:10:10	12.50	8.51
Native	7.66	7.15
LSD $_{(0.05)}$[‡]	2.21	
LSD $_{(0.05)}$[§]	6.45	

† Nitrogen rates shown are annual rates which were applied in six equal increments from May through November.

‡ Between nitrogen means at same root zone.

§ Between root zone at the same or different level of nitrogen.

CONCLUSIONS

The frequency of green rolling three times per week produced increased ball roll distance (BRD) without detriment to turfgrass quality. It is important to note that greens were on a frequent sand topdressing program. It is conceivable that if sand topdressing was not applied rolling may have negatively impacted soil physical properties and reduced turfgrass quality. Therefore, prior to initiating or suggesting a green rolling program of three times per week, consideration should be taken as to whether or not greens are on a frequent sand topdressing program.

More money is spent trying to manage dollar spot than any other turfgrass disease [Vargas, 1994] and lightweight rolling consistently resulted in less dollar spot, most notably in the predominantly sandy root zones. Though some would argue that no amount of disease activity is tolerable, reductions in disease pressure could decrease the rate or frequency of fungicide applications required for adequate disease control [Williams and Powell, 1995]. While there are numerous theories as to why rolling reduced dollar spot no valid conclusion can be made from data collected in this study. Lightweight rolling also resulted in fewer broadleaf weeds and bird beak intrusions.

Prior to the study it was hypothesized the lower rate of nitrogen (146 kg ha^{-1} $year^{-1}$) would result in increased color ratings in native root zones compared to the other two root zones due to greater nutrient retention. However, color and quality ratings resulted in no meaningful differences regarding the three different root zones. Greens with less soil generally had greater dollar spot symptoms. This supports observations by Couch and Bloom that higher soil moisture may reduce dollar spot development [Vargas, 1994].

The lower rate of nitrogen had significantly greater BRD than the higher rate of nitrogen. There was also a trend as the difference in ball roll distance increased between the two nitrogen rates with differences of 8cm in 1998, 10cm in 1999, and 19cm in 2000. This may indicate the turf was becoming thinner with time at the lower N rate. Nitrogen rate consistently resulted in significant differences in dollar spot counts, but the amount of time that passed after the nitrogen application appeared to be a factor. The higher rate of nitrogen resulted in fewer dollar spot infections when nitrogen fertility averaged 14 days after application. The lower rate of nitrogen resulted in fewer dollar spot infections when nitrogen fertility averaged 32 days after application. This data supports the notion that light frequent applications of nitrogen are best for controlling the disease especially during periods of warm weather [Vargas, 1994]. Higher nitrogen rates also resulted in more bird beak intrusions as compared to the lower nitrogen rate. If the bird beak intrusions were due to cutworm activity it makes sense the black cutworm moth would lay eggs in a succulent site for the best camouflage and nutrition of its young (verbal communication with Terry Davis).

Significant localized dry spot (LDS) differences were observed in 2000. The higher nitrogen rate resulted in a larger % LDS than the lower nitrogen rate. At the higher rate LDS was reduced with the practice of rolling. The native soil and 80:20 root zones had more LDS than the 80:10:10 root zone.

Potassium had no affect on color, quality, dollar spot, bird peak intrusions, LDS, or BRD. Additionally, BRD differences between the three rates of K averaged 3cm indicating the Stimpmeter can be utilized with a high degree of precision.

REFERENCES

Anonymous, 1926. Rolling the fairways and putting greens. Bulletin of the Green Section of the U.S. Golf Association. 6(3): 59.

Beard, J. B., 1994. Turf rolling. Grounds Maintenance. 29(1) 44,46,48,52.

DiPaola, J. M. and C. R. Hartwiger, 1994. Ball roll distance, rolling and soil compaction. Golf Course Management. 62(9): 49-51,78.

Duich, J. M. 1983. Management factors affecting putting ball roll distance. *In* Proc. 53rd Michigan Turfgrass Conf., Vol 12, East Lansing, MI, 18-19 Jan. 1983 p. 76-77.

Hamilton, G. W. Jr.; D. W. LivinBRDton, and A. E. Grover. 1994. The effects of light-weight rolling on putting greens. Science and Golf II, p. 425-430.

Harbin, W. S., 1922. The effect of trampling and rolling on turf. Bulletin of the Green Section of the U.S. Golf Association. 2(5): 148-150.

Hamilton, G. W., D. W. LivinBRDton, and A. E. Gover. 1994. The effect of light-weight rolling on putting greens. Science and Golf II, p.425-430.

Hammerschmidt, R. 1999. Phytoalexins: what have we learned after 60 years? Annu. Rev. Phytopathol. 37:285-306.

Hartwiger, C., 1996. The ups and downs of rolling putting greens. USGA Green Section Record. 34(4): 1-4.

Hummel, N. W. 1993. Rationale for the revisions of the USGA green construction specifications. USGA Green Section Record. March/April: 7-21.

Karcher, D., T. A. Nikolai, and R. N. Calhoun. 2001. Golfers' perceptions of greens speeds vary. Golf Course Management 69(3):57-60.

Kuehl, R. O. 1994. Statistical principles of research design and analysis. Duxbury Press. Belmont, CA.

Lodge, T. A. and S. W. Baker. 1991. The construction, irrigation, and fertiliser nutrition of golf greens. II. Playing quality during the first year of differential irrigation and nutrition treatments. J. Sports Turf Res. Inst. 67: 44-52.

Marschner, H. 1995. Mineral nutrition of higher plants 2nd Ed. Academic Press Inc., San Diego, CA.

Nikolai T. A., P. E. Rieke, J. N. Rogers, III, and J. M. Vargas Jr. 2001. Turfgrass and soil responses to lightweight rolling on putting green root zone mixes. Int. Turf. Soc. Res. J. 9:604-609.

Piper, C. V. and R. A. Oakley. 1921. Rolling the turf. Bulletin of the Green Section of the U.S. Golf Association. 1(3): 36.

Potter, D. A. 1998. Destructive turfgrass insects: Biology, diagnosis, and control. Ann Arbor Press, Chelsea, MI.

Rieke, P. E. and M. T. McElroy. 1986. Turfgrass soil management research report-1985: [IV. Effect of topdressing program and nitrogen fertility on Penneagle creeping bentgrass green]. *In* Proc. 56th Michigan Turfgrass Conf., Vol 15, East Lansing, MI, 13-15 Jan. 1986 p. 7,9-10.

Smiley, R. W. 1983. Compendium of turfgrass diseases. The American Phytopathological Society, St. Paul, MN.

Throssell, C. S. and J. M. Duich. 1981. Management factors affect golf course ball roll distances. Science in Agriculture 28(4):9.

USGA Greens Section Staff. 1996. Stimpmeter instruction booklet. USGA Golf House, Far Hills NJ.

Vargas, J. M. Jr. 1994. Management of turgrass diseases. 2nd ed. Lewis publishers, Boca Raton, FL.

Williams, D. W. and A. J. Powell Jr. 1995. Dew removal and dollar spot on creeping bentgrass. Golf Course Management 63(8):49-52.

CHAPTER THREE

RESPONSE OF PUTTING GREEN GRASS AND ROOT ZONE TO FERTILTIY AND ROLLING

ABSTRACT

A four-factor study (root zones split for rolling and split for nitrogen and potassium fertility) was utilized to study turfgrass growth and plant tissue and soil chemical analysis of three common putting green construction methods. Research greens were constructed with three different root zones: an 80:20 (sand: peat v/v) mixture constructed to USGA recommendations; an 80:10:10 (sand: soil: peat v/v) mixture 0.3m deep built with subsurface tile drainage; and a undisturbed sandy clay loam native soil green. Lightweight rolling consisted of plots rolled 3x/week and not rolled. Nitrogen rates were 146 and 293 kg ha^{-1} $year^{-1}$ and potassium treatments were 0, 195, and 390 K_2O kg ha^{-1} $year^{-1}$. The study took place 3-7 years after the greens were seeded with 'Penncross' creeping bentgrass (*Agrostis palustris* Huds.). All root zones were on a frequent sand topdressing program that accumulated in depth from 21-43mm over the length of the study.

All four years soil chemical analysis data were collected the native soil root zone had higher levels of P, K, Ca, Mg, than the soil-less 80:20 root zone. However, few significant differences resulted between the 80:20 root zone and the 80:10:10 root zone. The reason the 80:10:10 root zone did not result in consistently greater nutrient retention compared to the 80:20 root zone was most likely because differences in the cation exchange capacities were minimal and soil test samples included the sand topdressing layer (STL).

Approximately 75% of the roots were located in the STL regardless of the original root zone. Additionally, the native root zone had fewer roots in the 7.6-15.2cm depth than the sandy root zones.

The native root zone resulted in significantly more plant tissue K than the 80:20 root zone from 1997-1999. In 2000 no significant differences resulted from any of the root zones for any of the plant tissue nutrients. This could possibly be due to the fact that the STL was 43mm deep in 2000.

Pooled root zone data resulted in few significant and no meaningful differences in clipping weights. However, rolling resulted in significantly less clippings the majority of the time and root zone by rolling interactions indicated the majority of the decrease was attributed to reduced clippings on the rolled 80:10:10 root zone. Rolling resulted in no consistent trends on soil tests and plant nutrient analyses. However, rolling significantly increased the amount of roots in the STL both years data was taken.

The higher N rate decreased soil test K and P from 1998-2000. Clipping yields and plant tissue analyses indicate the decrease in soil K may be the result of increased growth and nutrient uptake related to the higher N rate. Results of plant tissue P were not consistent.

Soil test K increased with increasing K_20 fertility rates but fertility did not have a significant effect on any of the other cations reported in the soil test results. Though not always significant, the lowest K_2O rate resulted in higher % Ca and %Mg in the plant tissue. Potassium had no effect on clipping weights but did result in increased root growth one year in the STL.

INTRODUCTION

After World War II the game of golf became increasingly popular [Beard, 1994]. With this increase in play many native soil greens did not perform well because they did not posses adequate permeability [Garman, 1952]. The 1950's were a decade of research that led to the development of the United States Golf Association (USGA) Green Section Specifications [Hummel, 1993]. The underlying principles associated with the USGA greens include the necessity of a drainage system to move excess water quickly from the site and a layered profile to create a perched water table for the conservation of moisture and nutrients in the root zone [Snow, 1993].

The majority of greens built since 1960 have been under the guidelines of the USGA recommendations and industry concerns have led to three revisions [Snow, 1993]. The latest revision included soils suitable for the mixing into the predominantly sand-based mix [Hummel, 1993]. Undoubtedly, the primary reason for adding soil to the mix is nutrient and moisture retention.

Sands are free draining but the presence of nutrients naturally occurring in sand is limited and leaching potential is great which means greater care and management is required in the nutrition of sand greens [Isacc and Canaway, 1987]. Zontek [1990] wrote that green mixes should be prepared with soil to provide some silt and clay to improve nutrient availability.

Certainly, fertilizer recommendations have changed over the years. In 1912 Hall wrote that no fertilizer containing potash should ever be used on golf course putting greens [Isaac and Canaway,, 1987]. Oakley [1925] suggested the possibility for the use of potassium but stated where a sufficiency of K existed none should be supplied. Work performed by Christians *et al.* [1979] led them to conclude the role of potassium may play a more important role in turfgrass fertilization than previously realized. They noticed that as the level of K increased less N was required to attain maximum quality and concluded that additional work under field conditions was required to evaluate the importance of the interaction [Christians, *et al.*, 1979].

Although the effects of K on turfgrasses have been studied for decades there is no consensus among turfgrass managers as to the proper K fertilization rates [Sartain, 2002]. Furthermore, no one has yet determined with any precision what soil levels of P or K are optimum for turfgrass growth [Turgeon,1996]. Many turfgrass managers believe increasing K rates relative to N will lead to improved disease resistance, heat, drought, and wear tolerance, and will enhance root growth. The analyses of turfgrass commercial fertilizers reflect the change in philosophy regarding K fertilization. Twenty years ago a common analysis was 23-3-3, but today analysis such as 20-3-15 and 30-0-30 are common as turf managers are being extreme by applying high levels of K and very low levels of N [Christians, 1998].

So while it is true that the relationship of nutrients in sand greens has received considerable attention [Christians *et al.*, 1981, Isaac and Canaway, 1987, Dahlsson 1993, and Mitchel *et al.*, 1978] there is further need for detailed nutrient management studies and the issue of potassium management in sand putting greens is urgently needed [Kussow, 1995]. Standard values for turfgrasses need to be established based on density, color, and other components of turf quality as well as growth and how a nutrient level could affect stress tolerance as very little research has been conducted on these relationships. [Carrow *et al.*, 2001]

Soil mixtures with grasses suitable for British Isles putting green conditions have been evaluated under different fertility regimes [Lodge *et al.* 1991, Lodge and Dawson 1993]. However, little data are available regarding the response of creeping bentgrass (*Agrsotis palustris* Huds.) maintained at putting green height to varying fertility levels growing on different soils.

The objectives of this research were to compare the growth and soil and plant nutrient content of putting green turf under Michigan climatic conditions on differing soil types receiving different rates of nitrogen and potassium fertilizer.

MATERIALS AND METHODS

The research was conducted at the Hancock Turfgrass Research Center on the campus of Michigan State University, East Lansing, Michigan on a 1,388 m^2 (36.6 x 36.6m) experimental putting green constructed in 1992 and seeded with 'Penncross creeping bentgrass (*Agrostis palustris* Huds.) in spring, 1993. The three root zone mixes were: an 80:20 (sand: peat v/v) mixture constructed to USGA green recommendations; an 80:10:10 (sand: soil: peat v/v) mixture 0.3m deep built with subsurface tile drainage; and an undisturbed sandy clay loam (58% sand, 20.5% silt, and 21.5% clay) native soil green. The cation exchange capacity of the root zones was 5.8, 6.7, and 9.6 me/100g, respectively. Michigan peat was used in both sand mixes. Both sands were within USGA specifications for putting green root zone mixes (Table 1).

Each putting green was 148.8 m^2 (12.2 x12.2 m). They were arranged in a randomized complete block design with three replications of each green. Each 12.2 x 12.2m green had four Rain Bird Maxi Paw irrigation heads model number 2045A (Rain

Bird Distribution. Co. CA) at the corners for individual plot irrigation. Irrigation was applied on a daily basis with the exception of dry down periods to permit collection of data on the development of localized dry spot.

The experimental design was a split-split-plot, randomized complete block design. Main plots were root zone mixes split for rolling (rolled 3x/week and not rolled). Rolling was split for two nitrogen rates and three potassium rates. Greens were constructed with the specific purpose of comparing among different root zones managed under similar management regimes. Each green was split into two 10.4 x 5.2m greens that were mowed at 0.4cm cutting height six times per week with a walk-behind Toro GM 1000 (Bloomington, MN) greens mower.

One green from each construction plot was randomly selected and rolled three times per week (Monday, Wednesday, Friday) with an Olathe (Olathe Manufacturing Inc., Industrial Airport KS) lightweight green roller Model 396 from May through October 1997-2000. The other green in the same root zone block was not rolled and was utilized as a check. The Olathe roller had three smooth rollers that were 980 mm in length and 150 mm in diameter. The machine weighed 427 kg without an operator.

The fertility program design was a 2 x 3 factorial with two nitrogen levels (146 and 293 kg ha^{-1} $year^{-1}$) and three potassium levels (0, 195, and 390 kg ha^{-1} $year^{-1}$). The frequency and rates of application are reported in Table 36. The fertility programs were evaluated over 18 subplots (3 reps x 3 soils x 2 rolling regimes). In 1997 individual plots designated as 0 kg ha^{-1} potassium received potassium based on October 1996 soil test results. No further potassium was applied on the 0 potassium plots in 1998-2000. Each fertility plot was 4.7 m^2 (0.9 x 5.2 m). Fertilizer was applied with a LESCO (LESCO, Inc. Rocky River, OH) drop spreader model 012587 with a 0.9 m drop width. Methylene urea applied as Nutralene 40-0-0 (The Andersons, Maumee, OH) was the nitrogen source during the warmer months with urea applications being made in May and November of each year. Potassium sulfate (0-0-50) was the potassium source. Phosphorous (P) was not a factor in the study however; P data from soil tests and plant tissue analysis are reported. Triple superphosphate (0-46-0) was applied to the entire area when the common visual P deficiency (purpling of the leaf tissue) was observed on some plots. Applications of P took place in 1996 (49 kg ha^{-1} $year^{-1}$) 1998 (98 kg ha^{-1} $year^{-1}$) and 1999 (98 kg ha^{-1} $year^{-1}$).

Turfgrass clippings were collected in the bucket of the walk behind mower prior to fertility application from May through September. A single pass was made down the middle of each plot. Clippings were placed in a paper bag and oven dried at 60° C for 48 hours before recording the weights. Samples obtained in this manner in spring of each year were analyzed for plant tissue nutrient concentration prior to initiation of the annual fertility program. Total nitrogen of the clippings was determined using the micro-Kjeldahl procedure using Lachat flow injection analyzer [Horneck and Miller, 1998] and total spectrographic analysis was determined by dry ashing procedure samples analyzed using DCP [Miller, 1998].

In the fall of 1996, 1998, 1999, and 2000 soil samples were collected from each plot for soil chemical analysis with a 1.9cm diameter soil probe. After removal from the soil the verdure was removed and the succeeding 0-7.6 cm depth was used for chemical analysis. All plots were on a sand topdressing program and therefore each year more sand was in each sample. Six samples were taken form each plot. Extractable K, calcium (Ca), and magnesium (Mg) were determined with neutral (pH 7.0) 1M NH_4OAc (ammonium acetate) [Warncke and Brown, 1998]. Phosphorus was determined by the Bray and Kurtz P-1 extractant (0.03M NH_4F + 0.025 M HCl) to assess plant-available P[Frank *et al.*, 1998]. Soil pH was determined using a 1 soil: 1 water mixture with 1 drop of 1.0 M Ca Cl_2. [Watson and Brown, 1998].

August 1999 and 2000 root samples were collected from three depths (STL, 0-7.6cm, and 7.6-15.2cm) with a 3.2cm diameter soil probe. Three samples were taken from each depth on each fertility plot for root growth estimates. Roots were washed free of soil, oven dried at 65°C for 24 hours and weighed.

Analyses of variance for clipping and root weights and soil and plant chemical analysis were performed on pooled measurements followed by Fischer's protected Least Significant Difference (LSD) if differences were found at $P \geq 0.05$. The LSD was used to compare differences of mean numbers among the different treatments. All data were analyzed using MSTAT [1993] with the exception of standard error estimators for interactions in the split-split-plot design. Interactions were computed by hand with the appropriate degrees of freedom for interactions determined by the procedure introduced by Satterthwaite [Kuehl, 1994]. Numerous interactions occurred and only meaningful interactions that occurred on more than one date will be presented and discussed.

Table 36. Fertility frequency and rates in kg ha $^{-1}$, 1997 -2000†.

Treatment	May	June	July	Aug.	Sept.	Nov.
Nitrogen	48.8	48.8	48.8	48.8	48.8	48.8
Nitrogen	24.4	24.4	24.4	24.4	24.4	24.4
K_2O‡						
K_2O	48.7		48.7		48.7	48.7
K_2O	98.0	48.7	48.7	48.7	48.7	98.0

† Fertility study initiated in August 1996.
‡ In 1997 individual plots received soil test recommendations with 0 K_2O applied from 1998-2000.

RESULTS AND DISCUSSION

Soil Chemical Analyses

Soil samples for chemical analysis were taken in October 1996, 1998, 1999, and 2000. The pH levels of the 80:20, 80:10:10, and native root zones were 7.8, 7.8, and 7.7, respectively at the initiation and conclusion of the study (data not shown). The fertility study was initiated August 1996. The short duration between initiation of the study and the first sampling is most likely the reason no significant differences were observed regarding nitrogen (N) and potassium (K) rates in 1996 (Table 37). The native soil green had higher levels of phosphorous (P), K, Ca, and Mg, than the 80:20 root zone all four years (Tables 37-40). With the exception of Ca being lower in the 80:20 root zone in 2000 no significant differences were observed in soil tests between the 80:20 and the 80:10:10 root zones.

Higher N rates resulted in significantly less P and K in the root zones from 1998-2000. Increases in N rates have been shown to decrease P and K in root zones attributed to higher uptake of P and K associated with more vigorous growth and greater demand for nutrients [Colclough and Lawson, 1990]. Furthermore, since clippings are removed from the site there is no recycling of nutrients. In 1999 and 2000 higher N rates resulted in significant increases in the amount of Mg in the soil and in 1999 Ca also significantly increased with the higher N rate. Since less K was in the soil at the higher N rate, and Mg and Ca compete for exchange sites with K, it is intuitive that more Mg and Ca in soil tests would be the result. Consistent with increasing K fertility, higher soil test K were in the soil.

A two-way interaction between root zones and N rates on soil test K occurred in 1998 and 2000 (Table 41). In both years, N rate had no effect on the amount of K in the 80:20 root zone while the native soil had significantly less K at the higher N fertility rate. The 80:10:10 root zone had significantly less soil K with increasing N in 1998 but the difference was not significant in 2000. Furthermore, native soil had greater soil K at both N rates than the other two root zones both years. In 1998 the 80:20 had significantly less soil K than the 80:10:10, but there were no significant differences between the two in 2000.

Potassium rate x soil interactions from 1998 and 2000 are in Table 42. The native soil and 80:10:10 root zones had significantly more soil test K with increasing K rates. However, the 80:20 root zone resulted in no significant differences between the zero and 195 kg ha^{-1} rates both years interactions occurred. Regardless of the K fertility rate the native root zone had more soil K than the other two-root zones. In 1998 the zero K rate resulted in no significant difference between the 80:20 and 80:10:10 mixes but the 80:10:10 did have significantly more K than the 80:20 at the other two K fertility rates. In 2000, there were no significant difference between 80:20 and the 80:10:10 root zones at any K rate. Research conducted by Dest and Guillard [2001] suggests that release of K from primary minerals in some root zones with high sand content proceeds at rates to satisfy bentgrass requirement for K.

Table 37. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on soil chemical tests, October 1996.

		Soil chemical tests, kg ha^{-1}			
Root zone		P	K	Ca	Mg
80:20		26b	63b	2675b	288b
80:10:10		57ab	73b	2895b	276b
Native		98a	199a	3602a	619a
Significance		*	***	**	**
Rolling					
Rolled		60	105	3077	369
Not Rolled		61	117	3038	420
Significance		NS	NS	NS	*
Annual N rate§					
293 kg ha^{-1}		61	112	3095	404
146 kg ha^{-1}		60	111	3020	384
Significance		NS	NS	NS	NS
Annual K rate§					
0 kg ha^{-1}¶		63	112	3119	408
195 kg ha^{-1}		58	107	2990	381
390 kg ha^{-1}		60	116	3062	394
Significance		NS	NS	NS	NS
		Mean squares			
Source	df				
Replication	2	2855	1153	359956	49259
Root zone (S)	2	47160*	206848***	8437006**	1367587**
Error	4	5281	1925	575018	41843
Rolling (R)	1	86	4008	40200	71948*
SR	2	960	2304	55631	7385
Error	6	357	718	241915	6860
Nitrogen (N)	1	22	65	149669	9996
SN	2	249	605	13412	2554
RN	1	394	1449	37899	340
SRN	2	626	690	151224	2582
Potassium (K)	2	263	642	149089	6425
SK	4	69	356	19090	980
RK	2	160	803	61511	534
SRK	4	275	488	20159	835
NK	2	266	977	96918	602
SNK	4	112	453	69067	2059
RNK	2	20	1194	200330	3594
SNRK	4	342	533	73400	1886
Error	60	213	602	74466	3186

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

§ Fertility portion of research initiated August 1996.

¶ Soil test results from individual plots received soil test recommended rates of K in 1997.

Table 38. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on soil chemical tests, October 1998.

		Soil chemical tests, kg ha^{-1}			
Root zone		P	K	Ca	Mg
80:20		29b	45b	2915b	284b
80:10:10		63ab	67b	3178ab	265b
Native		97a	215a	3507a	582a
Significance		*	***	*	**
Rolling					
Rolled		63	108	3173	353
Not Rolled		63	110	3227	401
Significance		NS	NS	NS	**
Annual N rate					
293 kg ha^{-1}		60	100	3193	380
146 kg ha^{-1}		66	118	3207	374
Significance		*	***	NS	NS
Annual K rate					
0 kg ha^{-1}		66	80c	3166	379
195 kg ha^{-1}		61	99b	3218	379
390 kg ha^{-1}		61	148a	3216	372
Significance		NS	***	NS	NS
		Mean squares			
Source	df				
Replication	2	5023	1274	384367	25788
Root zone (S)	2	42072*	305815***	3161336*	1139051**
Error	4	4488	1158	417209	19772
Rolling (R)	1	1	148	81073	63803**
SR	2	71	1886	131378	10121
Error	6	681	504	98950	3249
Nitrogen (N)	1	817*	8503***	5635	1019
SN	2	251	2837***	5566	425
RN	1	5	340	23720	1994
SRN	2	198	231	22719	414
Potassium (K)	2	207	43370***	31167	627
SK	4	148	6312***	19449	3087
RK	2	68	77	67420	4024
SRK	4	15	220	54794	238
NK	2	296	146	2627	2347
SNK	4	151	365	28958	1923
RNK	2	85	20	4130	881
SNRK	4	73	421	73281	1784
Error	60	209	254	32533	1664

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table.39. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on soil chemical tests, October 1999.

		Soil chemical tests, kg ha^{-1}			
Root zone		P	K	Ca	Mg
80:20		45b	69b	2223b	281b
80:10:10		80ab	85b	2449b	265b
Native		113a	201a	3112a	484a
Significance		*	***	*	**
Rolling					
Rolled		78	121	2647	334
Not Rolled		81	116	2542	352
Significance		NS	NS	*	NS
Annual N rate					
293 kg ha^{-1}		75	107	2641	353
146 kg ha^{-1}		84	130	2548	334
Significance		**	***	*	**
Annual K rate					
0 kg ha^{-1}		83	77c	2582	346
195 kg ha^{-1}		77	120b	2633	348
390 kg ha^{-1}		78	158a	2570	335
Significance		NS	***	NS	NS
		Mean squares			
Source	df				
Replication	2	4561	9254*	651809	27641
Root zone (S)	2	41622*	185788***	7682524*	540469**
Error	4	3433	1191	489424	19894
Rolling (R)	1	294	558	297360*	8523
SR	2	336	972	221578*	668
Error	6	663	871	33070	4983
Nitrogen (N)	1	2366**	13694***	233258*	9888**
SN	2	233	2091**	88310	1467
RN	1	841	128	6897	810
SRN	2	32	488	6756	325
Potassium (K)	2	327	59467***	39913	1697
SK	4	223	6710***	15591	904
RK	2	274	416	21006	541
SRK	4	412	412	11980	1660
NK	2	115	1974**	95231	981
SNK	4	161	881*	28187	698
RNK	2	67	240	12152	514
SNRK	4	337	481	65655	1284
Error	60	258	286	36115	922

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 40. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on soil chemical tests, October 2000.

		Soil chemical tests, kg ha^{-1}			
Root zone		P	K	Ca	Mg
80:20		27b	66b	2642c	215b
80:10:10		56ab	71b	2993b	205b
Native		81a	217a	3623a	404a
Significance		*	***	**	**
Rolling					
Rolled		55	117	3110	267
Not Rolled		54	119	3061	283
Significance		NS	NS	NS	NS
Annual N rate					
293 kg ha^{-1}		48	108	3119	282
146 kg ha^{-1}		61	128	3053	268
Significance		***	***	NS	*
Annual K rate					
0 kg ha^{-1}		57	80c	3137	283
195 kg ha^{-1}		53	111b	3041	270
390 kg ha^{-1}		55	163a	3080	272
Significance		NS	***	NS	NS
		Mean squares			
Source	df				
Replication	2	4032	615	1089423	29254
Root zone (S)	2	26721*	263342***	8908812**	454309**
Error	4	3233	1131	268396	12538
Rolling (R)	1	28	173	65393	6772
SR	2	106	3162**	366430	7558
Error	6	233	241	298716	6617
Nitrogen (N)	1	4371***	10278***	119041	4632*
SN	2	836**	4416***	25985	983
RN	1	143	13	5782	119
SRN	2	323	304	54287	599
Potassium (K)	2	116	62359***	83379	1721
SK	4	28	10912***	44079	1062
RK	2	194	31	84099	1225
SRK	4	100	1270*	88011	1386
NK	2	30	1838*	41992	711
SNK	4	58	701	26183	727
RNK	2	43	52	92030	1861
SNRK	4	46	67	138129*	634
Error	60	125	422	54673	712

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 41. Soil potassium tests in kg ha^{-1} as affected by root zone and nitrogen rate†.

	October, 1998		October, 2000	
Root zone	293 kg ha^{-1} N	146 kg ha^{-1} N	293 kg ha^{-1} N	146 kg ha^{-1} N
80:20	44	46	64	68
80:10:10	60	74	66	76
Native	196	233	194	239
LSD $_{(0.05)}$ ‡	10.6		13.7	
LSD $_{(0.05)}$ §	13.6		14.8	

† Nitrogen rates shown are annual rates which were applied in six equal increments from May through November.
‡ Between nitrogen means at same root zone.
§ Between root zone at the same or different level of nitrogen.

Table 42. Soil potassium tests in kg ha^{-1} as affected by root zone and potassium rate†.

	October, 1998			October, 2000		
Root zone	0 kg ha^{-1}	195 kg ha^{-1}	390 kg ha^{-1}	0 kg ha^{-1}	195 kg ha^{-1}	390 kg ha^{-1}
80:20	30.4	42.0	63.4	48.6	60.7	88.7
80:10:10	45.2	59.5	97.0	44.8	67.2	100.9
Native	165.2	196.9	282.3	147.6	203.9	298.2
LSD $_{(0.05)}$ ‡		13.0			16.8	
LSD $_{(0.05)}$ §		15.5			17.7	

† Potassium rates shown are annual rates that were applied from May through November.
‡ Between potassium means at same root zone.
§ Between root zone at the same or different level of potassium.

Plant Tissue Nutrient Analyses

Plant tissue macronutrient analysis data from 1997-2000 are presented in Tables 43-46, respectively. Sufficiency ranges for nutrient concentrations in turfgrass are only general as specific ranges have not been developed for most turfgrass species and cultivars, yet all four years tissue nutrient analyses were taken every primary macronutrient fell within the common sufficiency range [Carrow *et al.*, 2001]. However, using creeping bentgrass sufficiency standards [Mills and Jones, 1996] the %N and %K were always below sufficiency standards while %P was within standard the first two years but decreasing to below sufficiency standards by the final year

In 1997-1999 the native root zone resulted in significantly higher tissue %K than the 80:20 root zone, which was only significantly different than the 80:10:10 root zone in

1998. That year the 80:10:10 root zone resulted in a higher %K in the plant tissue. In 2000 no significant differences resulted from pooled root zone data for %K in the plant tissue. The only other nutrients that were found at significantly different percentages in plant tissue regarding root zone were the P and sulfur (S) in 1999. Both nutrients were found in higher concentrations growing in turf in the native soil than in the 80:20 root zone with no difference between the predominantly sandy root zones.

Rolling resulted in minimal significant differences in tissue nutrient content. In 1998 rolling resulted in a significant increase in the amount of K in the tissue and in 1999 rolling resulted in a decrease in the amount of P.

Higher N fertility rates resulted in increased plant tissue N and K all four years. Since higher N rates also resulted in decreases in soil test K (Tables 38-40) the data is consistent with the theory that higher N rates may decrease root zone K because there is higher K uptake due to more vigorous growth and greater demand for nutrients [Colclough and Lawson, 1990]. Higher N rates also resulted in significantly less %Mg and %P in 1997 and %Ca in 2000. In 2000 the % P in the plant tissue increased with higher N rate, as did the % S.

As K fertility rates increased tissue K increased in 1997 and 1999 with decreases in the percentages of Ca and Mg in the plant tissue both of those years. No differences resulted in plant tissue nutrients as affected by K fertility in 1998. In 1999 zero-K fertility plots had significantly less in %K in leaf tissue than the 195 and 390 kg ha^{-1} K fertility rates with an inverse relationship resulting in an increase in the % Ca in the plant tissue.

The majority of interactions were not duplicated over years and no obvious trends from percentage of nutrients in leaf tissue were evident in interactions that occurred more than one year (data not shown).

Table 43. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on macronutrient content of *Agrostis palustris* cv. Penncross clippings, May, 1997.

		Percentage of nutrients in the leaf tissue					
Root zone		N	P	K	Ca	Mg	S
80:20		3.58	0.35	1.77 b	0.676	0.273	0.457
80:10:10		3.73	0.36	1.90 ab	0.660	0.257	0.431
Native		3.71	0.38	2.02 a	0.594	0.241	0.439
Significance		NS	NS	**	NS	NS	NS
Rolling							
Rolled		3.68	0.36	1.88	0.655	0.255	0.437
Not Rolled		3.67	0.36	1.91	0.632	0.260	0.447
Significance		NS	NS	NS	NS	NS	NS
Annual N rate							
293 kg ha^{-1}		3.81	0.36	1.94	0.637	0.253	0.443
146 kg ha^{-1}		3.54	0.37	1.85	0.650	0.261	0.442
Significance		***	*	***	NS	**	NS
Annual K rate							
0 kg ha^{-1}§		3.66	0.36	1.83 c	0.673a	0.262 a	0.442
195 kg ha^{-1}		3.70	0.37	1.90 b	0.643b	0.259 a	0.443
390 kg ha^{-1}		3.67	0.36	1.95 a	0.615c	0.251 b	0.442
Significance		NS	NS	***	***	***	NS
		Mean Squares					
Source	df						
Replication	2	0.141	0.002	0.112	0.057	0.001	0.010
Root zone (S)	2	0.243	0.007	0.577**	0.068	0.009	0.007
Error	4	0.189	0.014	0.027	0.053	0.008	0.006
Rolling (R)	1	0.007	0.000	0.034	0.014	0.001	0.003
SR	2	0.174*	0.012	0.137	0.011	0.000	0.005
Error	6	0.028	0.006	0.090	0.011	0.001	0.005
Nitrogen (N)	1	1.920***	0.002*	0.259***	0.004	0.002**	0.000
SN	2	0.043	0.002*	0.011	0.015*	0.001*	0.002
RN	1	0.065	0.000	0.007	0.000	0.000	0.000
SRN	2	0.003	0.000	0.009	0.001	0.000	0.001
Potassium (K)	2	0.012	0.001	0.141***	0.031***	0.001***	0.000
SK	4	0.008	0.000	0.004	0.000	0.000	0.001
RK	2	0.003	0.000	0.002	0.005	0.000	0.000
SRK	4	0.024	0.000	0.005	0.002	0.000	0.000
NK	2	0.004	0.000	0.000	0.002	0.000	0.000
SNK	4	0.017	0.000	0.013	0.003	0.000	0.000
RNK	2	0.001	0.000	0.002	0.000	0.000	0.000
SNRK	4	0.021	0.000	0.003	0.003	0.000	0.000
Error	60	0.017	0.0005	0.008	0.003	0.00015	0.001

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

§ Soil test results from individual plots received soil test recommended rates of K in 1997.

Table 44. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on macronutrient content of *Agrostis palustris* cv. Penncross clippings, May, 1998.

		Percentage of nutrients in the leaf tissue				
Root zone		N	P	K	Ca	Mg
80:20		3.81	0.31	1.75c	0.96	0.28
80:10:10		4.01	0.31	1.92b	0.83	0.24
Native		3.96	0.37	2.05a	0.67	0.23
Significance		NS	NS	**	NS	NS
Rolling						
Rolled		3.85	0.32	1.88	0.84	0.25
Not Rolled		4.00	0.34	1.94	0.79	0.25
Significance		NS	NS	*	NS	NS
Annual N rate						
293 kg ha^{-1}		4.26	0.33	1.94	0.79	0.25
146 kg ha^{-1}		3.59	0.33	1.88	0.84	0.25
Significance		***	NS	***	NS	NS
Annual K rate						
0 kg ha^{-1}		3.90	0.34	1.92	0.80	0.25
195 kg ha^{-1}		3.95	0.33	1.89	0.83	0.25
390 kg ha^{-1}		3.92	0.32	1.92	0.82	0.25
Significance		NS	NS	NS	NS	NS
		Mean Squares				
Source	df					
Replication	2	0.216	0.004	0.013	0.029	0.004
Root zone (S)	2	0.380	0.037	0.821**	0.857	0.023
Error	4	0.152	0.016	0.033	0.171	0.017
Rolling (R)	1	0.573	0.017	0.112*	0.066	0.000
SR	2	0.046	0.018*	0.019	0.194*	0.016
Error	6	0.106	0.004	0.017	0.040	0.004
Nitrogen (N)	1	12.369***	0.000	0.110***	0.076	0.001
SN	2	0.005	0.002	0.001	0.004	0.000
RN	1	0.026	0.003*	0.032	0.005	0.002
SRN	2	0.134	0.002	0.028*	0.029	0.000
Potassium (K)	2	0.024	0.002	0.009	0.006	0.000
SK	4	0.057	0.000	0.005	0.015	0.002
RK	2	0.189	0.002	0.026	0.051	0.002
SRK	4	0.026	0.000	0.004	0.012	0.001
NK	2	0.098	0.000	0.001	0.070	0.005
SNK	4	0.177	0.003**	0.043**	0.107*	0.007*
RNK	2	0.410**	0.000	0.008	0.119*	0.008*
SNRK	4	0.049	0.002**	0.015	0.084*	0.005*
Error	60	0.071	0.001	0.009	0.033	0.002

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 45. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on macronutrient content of *Agrostis palustris* cv. Penncross clippings, May, 1999.

		Percentage of nutrients in the leaf tissue					
Root zone		N	P	K	Ca	Mg	S
80:20		3.20	0.28 b	1.50 b	0.995	0.304	0.328 b
80:10:10		3.43	0.29 b	1.49 b	1.002	0.289	0.355 ab
Native		3.56	0.33 a	1.73 a	0.972	0.301	0.362 a
Significance		NS	**	*	NS	NS	*
Rolling							
Rolled		3.37	0.29	1.56	0.976	0.292	0.339
Not Rolled		3.36	0.30	1.59	1.003	0.304	0.358
Significance		NS	*	NS	NS	NS	NS
Annual N rate							
293 kg ha^{-1}		3.50	0.30	1.61	0.976	0.300	0.354
146 kg ha^{-1}		3.23	0.30	1.53	1.003	0.295	0.343
Significance		***	NS	***	NS	NS	NS
Annual K rate							
0 kg ha^{-1}		3.39	0.30 a	1.49 c	1.036 a	0.310 a	0.353
195 kg ha^{-1}		3.36	0.30 a	1.58 b	0.986 b	0.298 ab	0.344
390 kg ha^{-1}		3.52	0.29 b	1.66 a	0.947 b	0.286 b	0.348
Significance		NS	*	***	***	***	NS
		Mean Squares					
Source	df						
Replication	2	0.17	0.01	0.17	0.056	0.003	0.002
Root zone (S)	2	0.71	0.02**	0.70*	0.009	0.002	0.012*
Error	4	0.11	0.001	0.09	0.083	0.003	0.002
Rolling (R)	1	0.01	0.01*	0.03	0.019	0.004	0.010
SR	2	0.04*	0.00*	0.07	0.005	0.001	0.003
Error	6	0.01	0.001	0.06	0.012	0.002	0.002
Nitrogen (N)	1	1.90***	0.00	0.17***	0.020	0.001	0.003
SN	2	0.01	0.00	0.02	0.004	0.001	0.001
RN	1	0.00	0.00*	0.04*	0.023	0.002	0.001
SRN	2	0.01	0.00	0.02	0.067***	0.004**	0.001
Potassium (K)	2	0.01	0.00	0.26***	0.072***	0.005***	0.001
SK	4	0.00	0.00	0.14	0.008	0.000	0.001
RK	2	0.00	0.00	0.00	0.001	0.000	0.001
SRK	4	0.00	0.00	0.01	0.005	0.000	0.001
NK	2	0.00	0.00	0.02	0.004	0.000	0.001
SNK	4	0.01	0.00	0.00	0.001	0.000	0.001
RNK	2	0.00	0.00	0.01	0.004	0.000	0.000
SNRK	4	0.00	0.00	0.01	0.002	0.000	0.002
Error	60	0.01	0.0002	0.01	0.007	0.001	0.001

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 46. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on macronutrient content of *Agrostis palustris* cv. Penncross clippings, May, 2000.

		Percentage of nutrients in the leaf tissue.					
Root zone		N	P	K	Ca	Mg	S
80:20		2.88	0.27	1.71	2.107	0.603	0.342
80:10:10		2.99	0.28	1.75	2.074	0.607	0.336
Native		2.92	0.29	1.83	1.998	0.605	0.316
Significance		NS	NS	NS	NS	NS	NS
Rolling							
Rolled		2.95	0.29	1.78	2.075	0.604	0.332
Not Rolled		2.91	0.27	1.75	2.044	0.607	0.330
Significance		NS	NS	NS	NS	NS	NS
Annual N rate							
293 kg ha^{-1}		3.16	0.29	1.82	1.962	0.586	0.348
146 kg ha^{-1}		2.71	0.27	1.71	2.158	0.625	0.315
Significance		***	**	***	*	NS	***
Annual K rate							
0 kg ha^{-1}		2.90	0.28	1.61 b	2.230 a	0.639	0.331
195 kg ha^{-1}		2.94	0.28	1.82 a	1.966 b	0.585	0.334
390 kg ha^{-1}		2.96	0.28	1.87 a	1.984 b	0.592	0.329
Significance		NS	NS	***	*	NS	NS
		Mean square					
Source	df						
Replication	2	0.001	0.001	0.042	0.238	0.043	0.001
Root zone (S)	2	0.098	0.004	0.135	0.112	0.000	0.007
Error	4	0.241	0.001	0.024	2.129	0.165	0.003
Rolling (R)	1	0.041	0.000	0.026	0.026	0.000	0.000
SR	2	0.279*	0.002	0.110	0.056	0.002	0.002
Error	6	0.031	0.002	0.061	0.137	0.010	0.002
Nitrogen (N)	1	5.567***	0.005**	0.341***	1.040*	0.041	0.030***
SN	2	0.003	0.00	0.013	0.060	0.002	0.001
RN	1	0.009	0.002	0.043	0.002	0.000	0.001
SRN	2	0.046	0.000	0.003	0.108	0.008	0.000
Potassium (K)	2	0.033	0.000	0.731***	0.783*	0.030	0.000
SK	4	0.016	0.000	0.011	0.137	0.013	0.000
RK	2	0.017	0.000	0.011	0.127	0.010	0.000
SRK	4	0.017	0.000	0.022	0.275	0.022	0.000
NK	2	0.030	0.000	0.040	0.115	0.005	0.001
SNK	4	0.037	0.001	0.031	0.185	0.011	0.001
RNK	2	0.018	0.002	0.055	0.249	0.011	0.002
SNRK	4	0.016	0.000	0.018	0.209	0.014	0.000
Error	60	0.036	0.001	0.028	0.235	0.015	0.001

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Clipping Weights

Turfgrass clippings were collected on 15 dates from 1997-2000 (Tables 47-49). Of the 15 collection dates root zone resulted in significant data on only three occasions with no obvious trend resulting. On eight of the 15 dates rolling three times per week resulted in lower yields. Higher N fertility consistently produced more yields. Potassium had no effect on the amount of clippings.

Interactions repeated over the years included six soils x nitrogen rate interactions (Tables 50-51). In all six interactions the higher nitrogen rate resulted in more yield than the lower nitrogen rate for all three-root zones. Beyond that, no general trend applies though in most cases the native soil produced more clippings than the 80:20 with little difference between the 80:20 and 80:10:10. High yields are not necessarily the goal with turfgrasses [Carrow *et al.*, 2001], in fact lower yields are preferable as long as acceptable color, quality, and stress tolerances are maintained.

Seven soil x rolling interactions occurred in the data (Table 52-53). On all seven dates rolling resulted in no significant differences in yield in the native root zone and on only one date (17 June 1997) rolling resulted in fewer clippings in the 80:20 root zone. However, rolling consistently reduced the amount of clippings in the 80:10:10 root zone.

Table 47. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on clipping weights, 1997 and 1998.

		Clipping weight in grams					
		1997		1998			
Root zone		17 June	6 Oct.	5 May	13 June	22 July	27 Aug.
80:20		7.52	6.78	18.54	28.95	7.02	11.89
80:10:10		9.26	7.21	19.68	33.16	8.21	12.17
Native		8.28	7.72	20.85	33.39	8.76	13.33
Significance		NS	NS	NS	NS	NS	NS
Rolling							
Rolled		7.51	6.61	18.73	28.74	8.03	9.22
Not Rolled		9.20	7.86	20.65	34.93	7.97	15.70
Significance		**	**	*	*	NS	***
Annual N rate							
293 kg ha^{-1}		9.63	7.93	23.07	35.14	9.54	16.13
146 kg ha^{-1}		7.07	6.54	16.31	28.53	6.46	8.80
Significance		***	***	***	***	***	***
Annual K rate							
0 kg ha^{-1}		8.37	7.24	19.75	32.31	8.11	13.19
195 kg ha^{-1}		8.52	7.12	19.57	32.06	7.89	11.64
390 kg ha^{-1}		8.17	7.34	19.76	31.12	7.99	12.56
Significance		NS	NS	NS	NS	NS	NS
		Mean square					
Source	df						
Replication	2	0.35	3.05	73.16	215.04	18.96	122.23
Root zone (S)	2	27.30	8.05	47.96	225.40	28.37	21.15
Error	4	21.26	17.39	81.15	739.41	12.28	69.81
Rolling (R)	1	76.57**	41.81**	99.38*	1032.93*	0.08	1134.26***
SR	2	21.15*	38.19**	219.71**	322.55	2.59	51.37
Error	6	4.05	3.62	14.80	120.69	1.68	27.36
Nitrogen (N)	1	176.74***	52.36***	1234.92***	1180.08***	256.38***	1452.00***
SN	2	5.11*	1.99	21.44*	42.68	2.36	0.78
RN	1	0.19	0.65	16.18	117.40	0.72	17.93
SRN	2	3.02	0.54	3.76	72.72	0.80	32.26
Potassium (K)	2	1.11	0.45	0.40	14.12	0.42	22.01
SK	4	1.00	1.80	0.19	57.69	0.37	7.84
RK	2	1.55	2.17	4.33	3.45	1.21	21.18
SRK	4	1.99	1.22	3.85	77.66	0.40	9.20
NK	2	0.44	0.85	8.62	24.17	0.38	36.69
SNK	4	1.33	2.88	3.95	18.79	0.38	4.72
RNK	2	1.31	0.64	2.98	23.09	0.23	15.68
SNRK	4	1.00	1.82	9.12	44.50	2.26	16.34
Error	60	1.19	1.76	5.30	33.47	1.27	22.53

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 48. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on clipping weights, 1999.

		Clipping weight in grams				
Root zone		12 May	18 June	26 July	9 Sep.	7 Oct.
80:20		14.44	13.99	13.85	3.64	3.85
80:10:10		17.11	14.49	14.03	3.33	4.28
Native		22.60	15.25	17.59	3.64	5.03
Significance		*	NS	*	NS	NS
Rolling						
Rolled		17.85	14.42	14.72	3.17	3.97
Not Rolled		18.25	14.74	15.60	3.91	4.81
Significance		NS	NS	NS	*	**
Annual N rate						
293 kg ha^{-1}		20.44	17.01	17.07	3.83	5.71
146 kg ha^{-1}		15.66	12.14	13.54	3.24	3.07
Significance		***	***	***	***	***
Annual K rate						
0 kg ha^{-1}		18.21	14.45	15.44	3.67	4.66
195 kg ha^{-1}		17.89	14.77	15.01	3.47	4.37
390 kg ha^{-1}		18.05	14.51	15.02	3.47	4.14
Significance		NS	NS	NS	NS	NS
		Mean square				
Source	df					
Replication	2	52.61	20.57	23.56	9.45	2.93
Root zone (S)	2	623.48*	14.48	160.50*	1.12	12.97
Error	4	45.46	9.96	18.85	1.59	3.97
Rolling (R)	1	4.32	2.83	20.93	14.81*	19.34**
SR	2	67.65	18.15**	11.81	2.56	18.58**
Error	6	15.06	1.38	7.63	2.34	1.21
Nitrogen (N)	1	618.29***	639.43***	369.37***	9.48***	188.55***
SN	2	18.54	5.01*	10.17*	0.40	4.48
RN	1	18.53	1.38	1.81	0.33	1.36
SRN	2	3.91	4.17	5.67	0.58	1.15
Potassium (K)	2	0.93	1.04	2.19	0.45	2.44
SK	4	8.62	0.49	3.89	1.93*	0.64
RK	2	8.77	0.52	2.26	0.45	0.87
SRK	4	2.92	0.69	3.48	1.87*	0.26
NK	2	16.68	2.43	6.15	2.12*	0.45
SNK	4	27.96*	2.87	5.86	1.12	0.37
RNK	2	3.20	1.08	1.03	0.19	0.98
SNRK	4	9.00	1.70	4.39	1.69*	2.03
Error	60	8.88	1.48	3.25	0.61	1.64

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 49. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on clipping weights, 2000.

		Clipping weight in grams			
Root zone		15 May	20 June	24 July	6 Sep.
80:20		12.49	9.14	7.17	32.86
80:10:10		12.55	10.37	4.86	24.78
Native		14.58	11.62	4.16	30.42
Significance		NS	NS	**	NS
Rolling					
Rolled		12.99	8.43	5.42	25.65
Not Rolled		13.43	12.33	4.38	33.06
Significance		NS	***	NS	NS
Annual N rate					
293 kg ha^{-1}		16.03	13.02	7.25	39.04
146 kg ha^{-1}		10.39	7.74	3.55	19.67
Significance		***	***	***	***
Annual K rate					
0 kg ha^{-1}		13.56	10.31	5.37	28.86
195 kg ha^{-1}		13.32	9.92	5.53	29.64
390 kg ha^{-1}		12.75	10.91	5.29	29.56
Significance		NS	NS	NS	NS
		Mean square			
Source	df				
Replication	2	22.23	38.95	42.53*	767.59
Root zone (S)	2	51.00	55.63	89.16**	618.68
Error	4	19.23	138.82	3.18	1873.11
Rolling (R)	1	5.33	412.23***	0.04	1481.48
SR	2	41.98	108.83**	11.79**	666.23
Error	6	8.81	9.94	0.72	338.51
Nitrogen (N)	1	857.90***	751.03***	370.37***	10130.70***
SN	2	14.38*	1.16	30.06***	150.73
RN	1	3.63	13.65	1.97	151.70
SRN	2	1.15	14.60	0.97	360.73
Potassium (K)	2	6.21	8.83	0.52	6.56
SK	4	5.44	8.21	2.07	137.49
RK	2	5.70	3.94	0.65	121.56
SRK	4	5.66	4.14	1.54	115.61
NK	2	0.78	23.28	0.19	43.73
SNK	4	3.61	2.25	0.72	99.22
RNK	2	1.83	2.36	0.56	129.84
SNRK	4	10.59*	4.97	0.33	53.83
Error	60	3.48	8.49	1.70	138.02

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 50. Clipping weight (g) as affected by root zone and nitrogen rate†, June, 1997-June, 1999.

	17 June 1997		5 May 1998		18 June 99	
Root zone	293 kg ha^{-1}	146 kg ha^{-1}	293 kg ha^{-1}	146 kg ha^{-1}	293 kg ha^{-1}	146 kg ha^{-1}
80:20	8.48	6.57	22.76	14.32	16.85	11.13
80:10:10	10.96	7.57	22.91	16.46	16.75	12.23
Native	9.46	7.09	23.55	18.15	17.43	13.07
LSD $_{(0.05)}$ ‡	0.73		1.53		0.78	
LSD $_{(0.05)}$ §	2.24		3.19		1.59	

† Nitrogen rates shown are annual rates that were applied in six equal increments from May through November.

‡ Between nitrogen means at same root zone.

§ Between root zone at the same or different level of nitrogen.

Table 51. Clipping weight (g) as affected by root zone and nitrogen rate†, July, 1999-July, 2000.

	26 July 1999		15 May 2000		24 July 2000	
Root zone	293 kg ha^{-1}	146 kg ha^{-1}	293 kg ha^{-1}	146 kg ha^{-1}	293 kg ha^{-1}	293 kg ha^{-1}
80:20	16.08	11.62	15.98	9.01	10.04	4.29
80:10:10	15.33	12.72	15.28	9.82	6.43	3.30
Native	19.81	15.38	16.82	12.35	5.28	3.04
LSD $_{(0.05)}$ ‡	1.20		1.24		0.89	
LSD $_{(0.05)}$ §	2.22		2.25		1.04	

† Nitrogen rates shown are annual rates that were applied in six equal increments from May through November.

‡ Between nitrogen means at same root zone.

§ Between root zone at the same or different level of nitrogen.

Table 52. Clipping weights in grams as affected by root zone and rolling†, June, 1997-June, 1999.

Root zone	17 June 1997		6 October 1997		5 May 1998		18 June 1999	
	Rolled	Not Rolled	Rolled	Not Rolled	Rolled	Not Rolled	Rolled	Not Rolled
80:20	6.44	8.60	6.35	7.51	18.88	18.20	14.43	13.55
80:10:10	7.80	10.72	5.47	8.94	15.87	23.49	13.55	15.43
Native	8.29	8.26	8.02	7.43	21.44	20.26	15.27	15.24
$LSD_{(0.05)}$‡	1.64		1.90		3.07		0.96	
$LSD_{(0.05)}$§	2.21		2.02		4.27		1.45	

† Rolling was applied three times per week from May till September with an Olathe lightweight green roller.
‡ Between rolling means at same root zone.
§ Between root zone at the same or different level of rolling.

Table 53. Clipping weights in grams as affected by root zone and rolling†, October, 1999-July, 2000.

Root zone	7 October 1999		20 June 2000		24 July 2000	
	Rolled	Not Rolled	Rolled	Not Rolled	Rolled	Not Rolled
80:20	3.53	4.17	9.01	9.27	7.49	6.84
80:10:10	3.09	5.47	6.78	13.97	4.22	5.51
Native	5.27	4.80	9.49	13.76	4.53	3.79
$LSD_{(0.05)}$‡	0.90		2.58		0.69	
$LSD_{(0.05)}$§	1.03		5.14		0.88	

† Rolling was applied three times per week from May till September with an Olathe lightweight green roller.
‡ Between rolling means at same root zone.
§ Between root zone at the same or different level of rolling.

Root Weights

Root weights collected 31 August 1999 and 28 August 2000 are presented in Table 54. Interestingly, regardless of parent root zone nearly ¾ of the root system was located in the STL. Ranges inclusive of years resulted in 68-72% of the roots in the STL, 20-25% at 0-7.6cm depth, and 6-9% located in the 7.6-15.2cm depth. The only significant effect of root zone occurred in the 7.6-15.2cm depth in 1999 as the native root zone had significantly less roots than the other root zones. The data in 2000 was similar but not significant.

Regarding the other three factors: 1) rolling resulted in an increase in the amount of roots in the topdress layer for both years; 2) the lower N rate resulted in more roots located in the 7.6-15.2 cm depth in 2000 and; 3) zero K plots had significantly fewer roots in the STL layer in 1999 with no differences between plots receiving annual K rates of 195 kg ha^{-1} and 390 kg ha^{-1}.

In 1999 a soil x K interaction resulted in the 80:20 root zone having significantly more roots than the native root zone at all K rates and more roots than the 80:10:10 at the highest and lowest K rates (Table 55). Furthermore, the 80:10:10 had significantly more roots at all K rates than the native soil. Potassium rate had no impact on root weights in the 80:10:10 and native root zone with the 195 kg ha^{-1} rate in the 80:20 root zone having significantly less roots than the zero and 390 kg ha^{-1} rates. Overall, the 80:20 at zero K was the only treatment to have significantly more roots than any other treatment.

In 2000 two three-way interactions occurred at the 7.6-15.2cm depth. Generally speaking, 80:20 root zone had more roots than the other two root zones (Figures 9-10.) with low N rolled plots receiving intermediate K resulting in the most roots in the 80:20.

Of the four factors, the most consistent data for both years was that rolling significantly increased the root mass in the STL layer and inclusive of interactions the 80:20 root zone had more roots at the 7.6-15.2cm depth than the native soil root zone.

Table 54. Main effects and mean squares for treatment effects of root zone, rolling, nitrogen and potassium fertilization on root weights.

		Root weight in grams					
		31 August 1999			28 August 2000		
Root zone		Topdress	0-7.6cm	7.6-15.2cm	Topdress	0-7.6cm	7.6-15.2cm
80:20		1.329	0.410	0.146a	1.192	0.345	0.146
80:10:10		1.573	0.465	0.126a	1.022	0.361	0.120
Native		1.430	0.484	0.085b	1.229	0.448	0.098
Significance		NS	NS	**	NS	NS	NS
Rolling							
Rolled		1.584	0.462	0.118	1.296	0.366	0.123
Not Rolled		1.303	0.444	0.120	1.000	0.403	0.120
Significance		*	NS	NS	**	NS	NS
Annual N rate							
293 kg ha^{-1}		1.381	0.433	0.120	1.138	0.382	0.113
146 kg ha^{-1}		1.506	0.473	0.118	1.158	0.388	0.130
Significance		NS	NS	NS	NS	NS	*
Annual K rate							
0 kg ha^{-1}		1.177b	0.494	0.118	1.173	0.407	0.128
195 kg ha^{-1}		1.629a	0.442	0.114	1.100	0.372	0.116
390 kg ha^{-1}		1.525a	0.423	0.125	1.170	0.375	0.121
Significance		**	NS	NS	NS	NS	NS
		Mean square					
Source	df						
Replication	2	4.373	0.921*	0.003	0.118	0.064	0.013
Root zone (S)	2	0.542	0.054	0.035**	0.439	0.110	0.021
Error	4	4.123	0.132	0.001	0.785	0.035	0.013
Rolling (R)	1	2.128*	0.009	0.000	2.364**	0.037	0.000
SR	2	1.363	0.291	0.002	0.184	0.177	0.001
Error	6	0.359	0.103	0.005	0.162	0.034	0.004
Nitrogen (N)	1	0.423	0.043	0.000	0.011	0.001	0.008*
SN	2	0.081	0.096	0.000	0.064	0.060	0.002
RN	1	0.093	0.004	0.006	0.020	0.069	0.005
SRN	2	0.525	0.076	0.001	0.117	0.015	0.006*
Potassium (K)	2	2.020**	0.049	0.001	0.062	0.013	0.001
SK	4	0.602	0.022	0.004*	0.074	0.044	0.004
RK	2	0.310	0.016	0.000	0.189	0.023	0.000
SRK	4	0.870	0.044	0.001	0.249	0.015	0.001
NK	2	1.010	0.029	0.000	0.038	0.017	0.002
SNK	4	0.511	0.032	0.002	0.019	0.029	0.005*
RNK	2	0.252	0.094	0.001	0.101	0.042	0.004
SNRK	4	0.182	0.152*	0.003	0.128	0.008	0.003
Error	60	0.436	0.060	0.001	0.143	0.022	0.002

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, nonsignificant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 55. Root weights in grams from 7.6 to 15.2 cm depth as affected by root zone and annual potassium rate†.

	31 August 1999		
Root zone	0 kg ha^{-1}	195 kg ha^{-1}	390 kg ha^{-1}
80:20	0.166	0.120	0.151
80:10:10	0.112	0.130	0.137
Native	0.075	0.093	0.087
$LSD_{(0.05)}$ ‡		0.021	
$LSD_{(0.05)}$ §		0.021	

† Potassium rates shown are annual rates that were applied from May through November.

‡ Between potassium means at same root zone.

§ Between root zone at the same or different level of potassium.

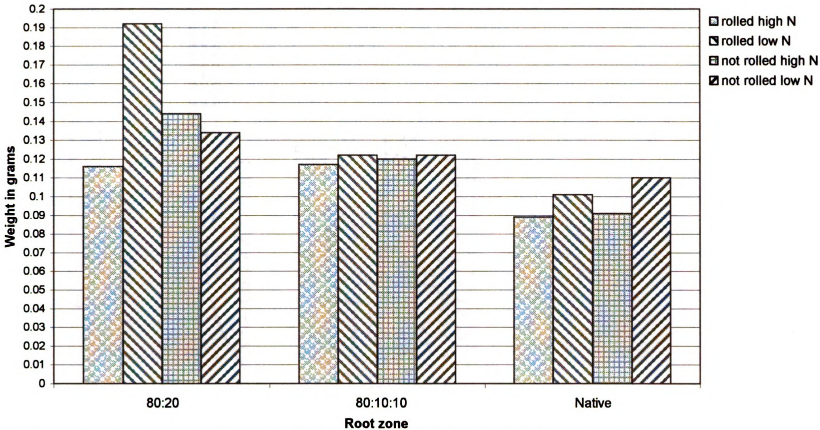

Figure 9. Interaction of root zone, rolling, and nitrogen on root weights in grams from 7.6-15.2 cm depth from a creeping bentgrass (Agrostis palustris Huds.) green 28 August, 2000.

LSD (0.05) = 0.04 (different levels of nitrogen at the same level of root zone and rolling.)
LSD (0.05) = 0.05 (different levels of rolling at the same level of root zone and nitrogen.)
LSD (0.05) = 0.07 (different levels of root zoneat the same or different level of rolling and nitrogen.)

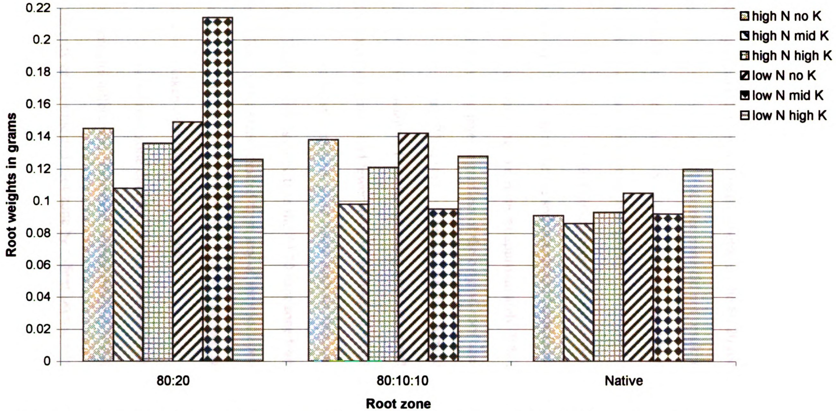

Figure 10. Interactions of root zone, nitrogen, and potassium on root weights in grams from 7.6-15.2 cm depth on a creeping bentgrass (Agrostis palustris Huds.) green 28 August, 2000.

LSD (0.05) = 0.05 (different levels of potassium at the same level of root zone and nitrogen.)
LSD (0.05) = 0.05 (different levels of nitrogen at the same level of root zone and potassium.)
LSD (0.05) = 0.07 (different levels of root zone and the same or different level of nitrogen and potassium.)

CONCLUSIONS

Each year of this study soil chemical analysis data were collected the native soil root zone had higher levels of P, K, Ca, Mg, than the soil-less 80:20 root zone. However, few significant differences resulted between the 80:20 root zone and the 80:10:10 root zone. The reason the 80:10:10 root zone did not result in consistently greater nutrient retention compared to the 80:20 root zone was most likely because soil test samples included the sand topdressing layer (STL).

Carrow, *et al.* [2001] noted (especially for cool-season grasses) most roots will be in the STL layer and therefore soil test should be inclusive of the STL layer. Data from this study supports their premise, as approximately 75% of the roots were located in the sand topdressing layer regardless of the original root zone. Considering the majority of roots were in the STL it is not surprising that few significant differences resulted in plant tissue nutrient analysis from turf growing in the three different root zones. Additionally, the native root zone had fewer roots in the deepest profile than the sand root zones.

The most consistent plant tissue analysis data was the native root zone resulted in significantly more tissue K than the 80:20 root zone from 1997-1999. In 2000 no significant differences resulted from any of the root zones for any of the plant tissue nutrients. At that time the mean STL was 4.3cm deep and soil samples for soil chemical test were taken from the 0-7.6cm depth.

Pooled root zone data for clipping weights resulted in few significant and no meaningful differences. However, rolling resulted in significantly less clippings the majority of the time and root zone by rolling interactions indicated that the majority of the decrease was attributed to the rolling effect on clippings from the 80:10:10 root zone.

Rolling resulted in no consistent trends on soil tests and plant nutrient analyses. However, rolling significantly increased the amount of roots in the STL both years data was taken.

The higher N rate decreased soil test K and P from 1998-2000. Clipping yields and plant tissue analysis indicates that the decrease in soil K may be the result of increased growth and nutrient uptake related to the higher N rate since clippings are removed. Results of plant tissue P were not consistent.

Soil test K increased with increasing K_20 fertility rates but fertility did not have a significant effect on any of the other cations reported in the soil test results. Though not always significant, the lowest K_2O rate resulted in higher % Ca and %Mg in the plant tissue. Potassium had no effect on clipping weights but did result in increased root growth one year in the STL..

REFERENCES

Beard, J. 1994. In search of the ultimate putting green. Greenkeeper Int. December:22-25.

Colclough, T., and D. M. Lawson. 1990. Fertiliser nutrition of sand golf greens. VII. Rootzone chemical analysis. J. of the Sports Turf Res. Inst. 66:100-108.

Carrow, R. N., D. V. Waddington, and P. E. Rieke. 2001. Turfgrass soil fertility and chemical problems: assessment and management. Sleeping Bear Press, Chelsea, MI.

Christians, N. E. 1998. Fundamentals of Turfgrass Management. Sleeping bear press, Chelsea, MI.

Christians, N.E., D.P. Martin, and K.J. Karnok. 1981. The interrelationship among nutrient elements applied to calcareous sand greens. Agron J. 73:929-933.

Christians, N.E., D. P Martin, and J. F. Wilkinson. 1979. Nitrogen, phosphorous, and potassium effects on quality and growth of Kentucky Bluegrass and creeping bentgrass. Agron. J. 71:564-567.

Dahlsson, S.O. 1993. Effects of four potassium sources at N:K ratios on putting greens. Int'l Turfgrass Soc. Res. J. 7:528-532.

Dest, W. M., and K. Guillard. 2001. Bentgrass response to K fertilization and K release rates from eight sand rootzone sources used in putting green construction. Int. Turf. Soc. Res. J. 9:375-381.

Frank, K., D. Beegle, and J. Denning. 1998. Phosphorus. p. 21-30. *In* B. Ellis et al. Recommended chemical soil test procedures for the North Central Region. - Missouri Agri. Expe. Sta. Columbia, MO.

Garman, W. L. 1952. Permeability of various grades of sand and peat and mixtures of these with soil and vermiculite. USGA J. Turf Manag. 6(1):27-28.

Horneck, D. A., and R. O. Miller. 1998. Determination of total nitrogen in plant tissue. P *In* Y. P. Kalra Handbook of reference methods for plant analysis. Soil and plant analysis council. CRC Press, Boca Raton, FL.

Hummel, N. W. 1993. Rationale for the revisions of the USGA green construction specifications. USGA Green Section Record. March/April: 7-21.

Issac, S.P., and P.M. Canaway. 1987. The mineral nutrition of Festuca-Agrostis golf greens:A review. J. Sports Turf Res. Inst. 63:9-27.

Kuehl, R. O. 1994. Statistical principles of research design and analysis. Duxbury Press. Belmont, CA.

Kussow, W. R. 1995. Some USGA putting green management issues. The Grass Roots. 23(3):44-445.

Lodge, T. A., S. W. Baker, P.M. Canaway, and D.M. Lawson. 1991. The construction irrigation and fertilizer nutrition of golf greens. I. Botanical and reflectance assessments after establishment and during the first year of differential irrigation and nutrition treatments. J. Sports Turf Res. Inst. 67:32-43.

Lodge, T. A., and D. M. Lawson. 1993. The construction irrigation and fertilizer nutrition of golf greens. Botanical and soil chemical measurements over three years of differential treatment. J. Sports Turf Res. Inst. 69:59-73.

Miller, R. O. 1998. High-temperature oxidation: dry ashing. p. 53-56. *In* Y. P. Kalra Handbook of reference methods for plant analysis. Soil and plant analysis council. CRC Press, Boca Raton, FL.

Mills, H. A., and J. B. Jones, Jr. 1996. Plant analysis handbook II. Athens, GA: Micro-Macro Publ., Inc.

Mitchell, W.H., A.L. Morehart, L.J. Cotnoir, B.B. Hesseltine, and D.N. LanBRDton, III. 1978.Effect of soil mixtures and irrigation methods on leaching of N in golf greens. Agron. J. 70:29-35.

Oakley, R. A. 1925. Fertilizers in relation to quality of turf and to weed control. Bulletin of the Green Section of the U.S. Golf Association. 5(3):50-56.

Sartain, J. B. 2002. Tifway bermudagrass response to potassium fertilization. Crop Sci. 42:507-512.

Snow, J. T. 1993. The whys and hows of revising the USGA green construction recommendations. USGA Green Section Record. March/April: 4-6.

Turgeon, A. J. 1996. Turfgrass management. 4th ed. Prentice-Hall, Inc. Upper Saddle River, NJ.

Warnke, D., and J. R. Brown, 1998. Potassium and other cations. P.31-34. *In* B. Ellis et al. Recommended chemical soil test procedures for the North Central Region. Missouri Agri. Expe. Sta. Columbia, MO.

Watson, M. E. and J. R. Brown. 1998. pH and lime requirement. P.13-16. *In* B. Ellis et al. Recommended chemical soil test procedures for the north central region. Missouri Agricultural Experiment Station. Columbia, MO.

Zontek, S. J. 1990. Managing fertility in high-sand-content greens. USGA Green Section Record 28(4):1-5.