USGA

Turfgrass and Environmental Research Online

...Using Science to Benefit Golf

Rutgers University researchers conducted two field trials, managed as putting green and fairway turf, to evaluate the performance of creeping and velvet bentgrass in mixed swards with annual bluegrass (*Poa annua* var. *reptans* Hausskn.) when subjected to traffic stresses. High density cultivars studied in these trials performed well under both putting green and fairway conditions.

Volume 7, Number 17
September 1, 2008

PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 450 projects at a cost of $29 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

Editor

Jeff Nus, Ph.D.
1032 Rogers Place
Lawrence, KS 66049
jnus@usga.org
(785) 832-2300
(785) 832-9265 (fax)

Research Director

Michael P. Kenna, Ph.D.
P.O. Box 2227
Stillwater, OK 74076
mkenna@usga.org
(405) 743-3900
(405) 743-3910 (fax)

Putting Green and Fairway Turf as Affected by Traffic

H. Samaranayake, T. J. Lawson, and James A. Murphy

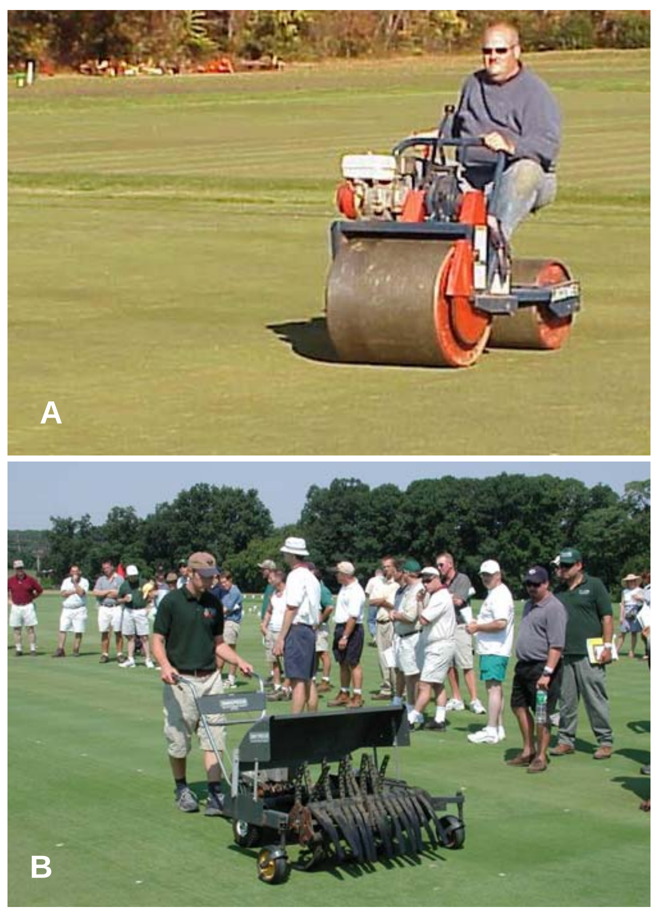
SUMMARY

Creeping bentgrass (*Agrostis stolonifera* L.) has received more study and use as golf course turf than velvet bentgrass (*A. canina* L.). The objective of two field trials, managed as putting green and fairway turf, was to evaluate the performance of creeping and velvet bentgrass in mixed swards with annual bluegrass (*Poa annua* var. *reptans* Hausskn.) when subjected to traffic stresses.

- The compactive forces of rolling produced greater detrimental soil physical and turf responses in the fairway trial than the putting green trial. This was probably a result of differences in surface resiliency in the thatch-mat layers as a result of topdressing the putting green turf.
- Turf quality, turf density, and bentgrass populations for most cultivars were typically more susceptible to wear stress than compaction, particularly in the putting green trial. Thus, traffic control (such as the change from metal to plastic spikes on golf shoes) and other management strategies that alter wear damage (thinning) may have a greater impact on turf quality and bentgrass populations in mixed stands than practices intended to manage compaction, particularly on well-drained soil.
- The tolerance of velvet bentgrass to traffic stresses was much greater than reputed. In fact, this species performed and resisted the spread of annual bluegrass better than most cultivars of creeping bentgrass.
- High density cultivars studied in these trials performed well under both putting green and fairway conditions; 'Vesper', '7001', and 'Penn A-4' had the best overall performance of cultivars.
- Interactions indicated that turf quality of 'SR 7200' was consistently susceptible to compaction in the fairway trial, and bentgrass population of 'Penn G-2' was consistently susceptible to wear stress in both trials and compaction stress in the fairway trial.
- Performance of 'Providence' in both trials indicated susceptibility to compaction. 'Pennlinks' and 'Penncross' were ineffective at maintaining large bentgrass populations regardless of the type of traffic particularly in the putting green trial.

Golf course putting greens and fairways are subjected to traffic stresses with wear and compaction being two of the most common components of traffic (9). Creeping bentgrass is considered to be less tolerant of wear and stresses resulting from soil compaction than many other turfgrass species (11), but genetic-based differences in traffic tolerance occur within species, as well as across species (8, 13, 14, 28, 33, 34). It is also recognized that species compositions of swards can change in response to traffic (7, 15, 17, 24).

The ability of bentgrass cultivars to maintain a dense turf cover, as well as recover from traffic stresses, can influence resistance to weed invasion (10). Annual bluegrass is an invasive winter annual species with very high seedling growth rate (18). Annual bluegrass can invade cool-season species subjected to wear (7) and become the dominant species on golf courses in



Compaction treatments were applied using either a 0.6-m wide 432-kg water-filled turf roller (A) or a 0.8-m wide 1,173-kg vibratory pavement roller, and wear was applied using a 0.8-m wide wear simulator constructed from a modified walk-behind power broom (B).

H. SAMARANAYAKE, Ph.D., Research Technician; T. J. LAWSON, Research Technician; and JAMES MURPHY, Ph.D., Associate Extension Specialist; Department of Plant Biology and Pathology, Rutgers University, New Brunswick, NJ.

USGA Turfgrass and Environmental Research Online 7(17):1-15.
TGIF Record Number: 138914

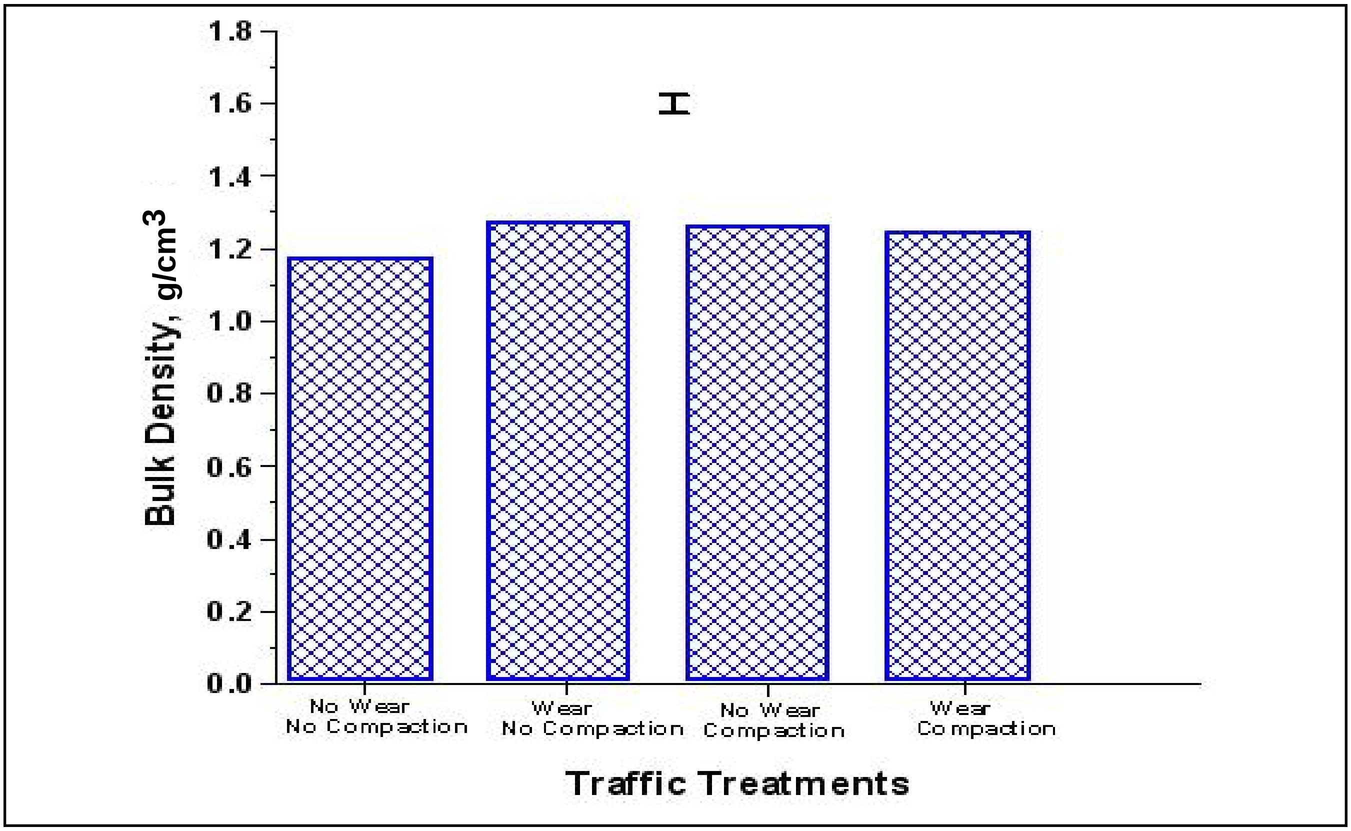


Figure 1. Bulk densities of 0- to 51-mm surface depth as affected by traffic on a putting green grown on a sandy loam in 2001.

mild temperate and sub-arctic climates (2).

Beard (2) characterized annual bluegrass as an opportunistic grass which becomes established in turfs of non-aggressive bentgrass cultivars. Reports have demonstrated that creeping bentgrass cultivars vary in turf density (12, 26) and the ability to resist annual bluegrass invasion under non-trafficked conditions (3, 19). The relative dominance of bentgrasses in a sward mixture with annual bluegrass under traffic has not been reported.

Creeping bentgrass has been more extensively studied for golf course turf (3, 12, 29) than velvet bentgrass (10). Velvet bentgrass produces a very high density turf but is reputed to be soft (16) with a strong thatching tendency (2), characteristics which influence traffic tolerance. The release of the cultivar 'SR 7200' has aroused interest in the use of velvet bentgrass for golf turf (6). Trials at Sports Turf Research Institute in Bingley, UK have shown improved wear tolerance of velvet bentgrass compared with many creeping or colonial bentgrass varieties (27). Trials including velvet bentgrasses in New Jersey also indicate velvet bentgrass has broader adaptation for golf turf (5).

The objective of this research was to assess the performance of bentgrass cultivars in a sward mixed with annual bluegrass when subjected to wear and/or compaction on simulated golf course putting green and fairway turf.

Experimental Design and Treatments

Two studies were conducted. One study was managed as putting green turf, and the other was maintined as fairway turf. Trials were initiated on a sandy loam (fine-loamy, mixed, mesic Typic Hapludults) at a research facility in North Brunswick, NJ.

Both trials used split-plot designs with main plots (wear and compaction) arranged as 2 x 2 factorials. Wear at two levels (no-wear and wear) and compaction at two levels (no com-

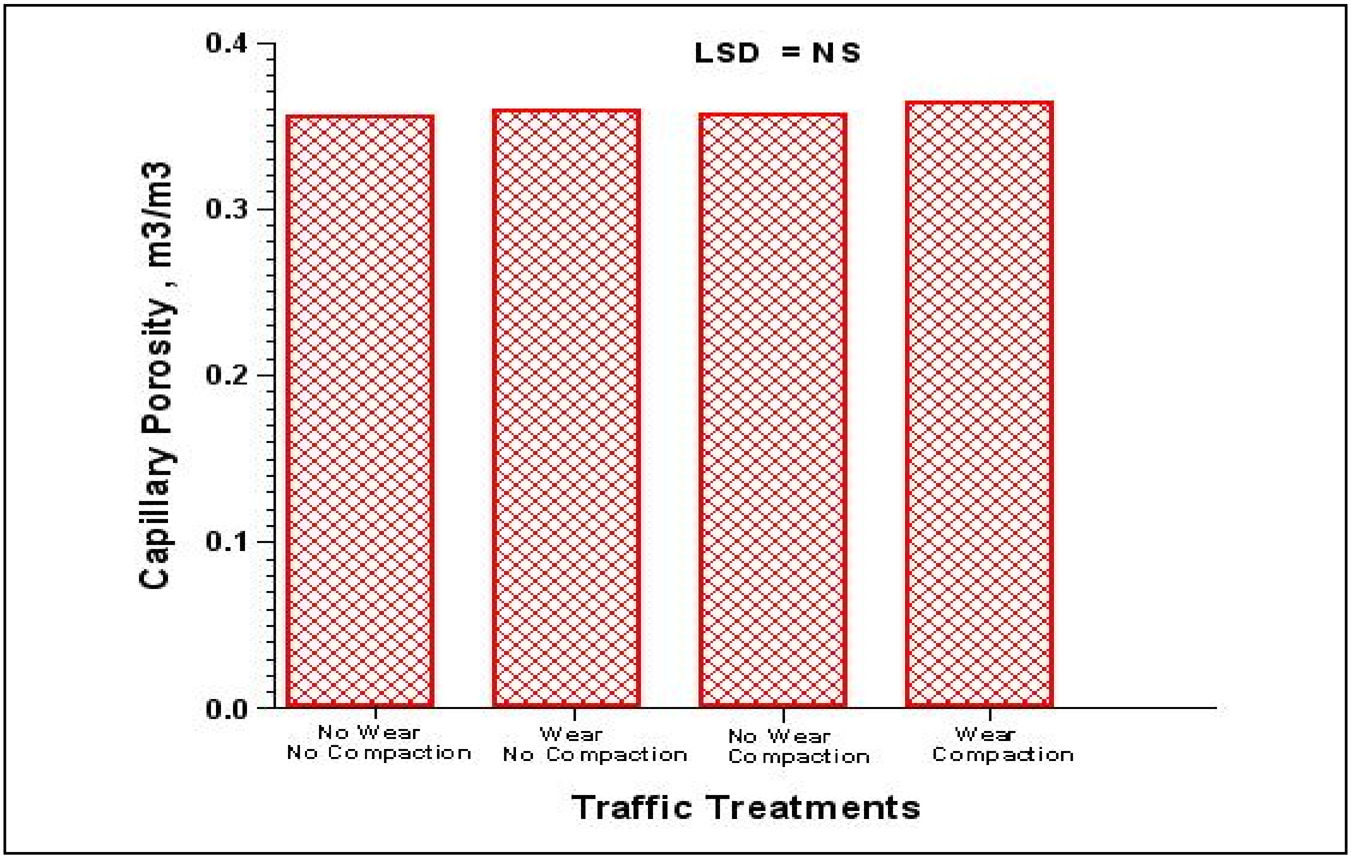


Figure 2. Capillary porosities of 0- to 51-mm surface depth as affected by traffic on a putting green grown on a sandy loam in 2001.

paction and compaction) were randomly assigned to main plots (1.5 x 17.0 m). Fifteen cultivars of two species (creeping bentgrass and velvet bentgrass) were randomly assigned to subplots (1.5 x 0.9 m). The twelve creeping bentgrass cultivars evaluated in the putting green study were: 'L-93', 'Penn A-4', 'Penn G-2', 'Century', 'SR 1119', 'Providence', 'Southshore', 'SR 1020', 'Penneagle', 'Putter', 'PennLinks', and 'Penncross'. Velvet bentgrass entries were: 'SR 7200', '7001' (an experimental selection from the New Jersey Agric. Exp. Stn.), and 'MVB' later released as 'Vesper'. The fairway study evaluated the same cultivars except that 'Vesper' was substituted (due to shortage of seed) with 'Penn G-1' creeping bentgrass. The putting green study was replicated four times and the fairway study three times.

Before seeding the bentgrasses in each trial, the entire plot area was topdressed with soil cores taken from putting greens of Plainfield Country Club (Plainfield, NJ) that contained seeds of annual bluegrass. Cores were stockpiled for one year to kill bentgrass vegetation. The cores were spread onto the soil surface and hollow tine cultivated and verticut to incorporate the cores into the soil. Creeping bentgrass cultivars were seeded at 3.6 g m^{-2} and velvet bentgrass at 2.1 g m^{-2} based on number of seeds per unit area. An unseeded subplot was included. Volunteer establishment of bentgrass in unseeded subplots was negligible. The initial soil pH value was 6.0 and available (Mehlich 3) P and K were 22.2 and 36.5 g m^{-2} respectively. Irrigation was applied only when wilt stress was imminent to maintain relatively dry soil conditions and to wash-in fertilizer. Fungicides were applied as needed to avoid disease stress.

The putting green trial was seeded on September 30, 1998. It was fertilized with 4.9, 2.1, 4.1 g m^{-2} of N, P, and K respectively on September 30, 1998. Two post-plant fertiliza-

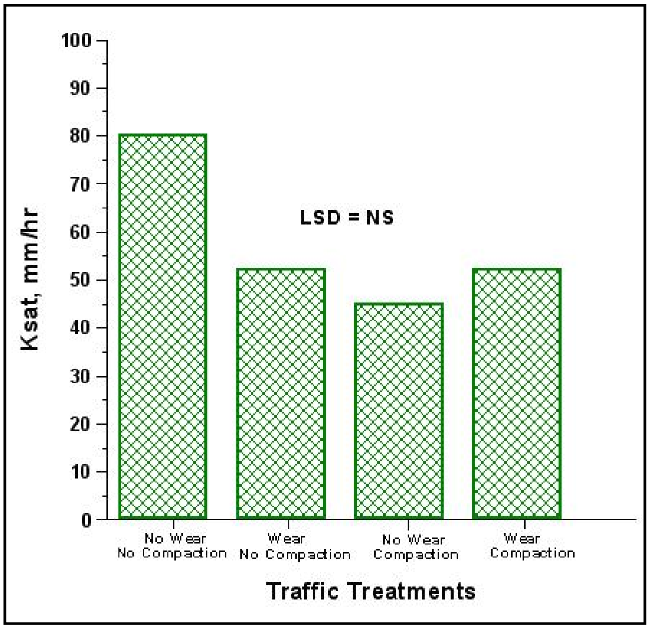


Figure 3. Saturated hydraulic conductivities of 0- to 51-mm surface depth as affected by traffic on a putting green grown on a sandy loam in 2001.

tions applied 7.5, 2.4, and 5.2 g m^{-2} of N, P, and K, respectively. Fertilizer treatments (19 times) applied a total of 26.1, 7.1 and 12.7 g m^{-2} of N, P, and K, respectively in 1999; 6.4, 1.1, and 2.0 g m^{-2} of N, P, and K, respectively, in 2000 (4 times); and 14.1, 4.5, 9.3 g m^{-2} of N, P, and K, respectively, in 2001 (9 times).

Mowing of the putting green was initiated on November 7, 1998 at 15.7 mm and the height was gradually lowered to 3.6 mm on June 12, 1999 and 3.1 mm on March 23, 2000. Mowing was performed 6 times per week with clippings removed. The study was topdressed eight times from April to December 1999 for a total of 10.9 L m^{-2} with medium-sized sand conforming to USGA size guidelines (17). Two topdressings were applied each in 2000 and 2001 totaling 1.7 L m^{-2} and 1.9 L m^{-2}, respectively. Solid tine cultivation was performed before topdressing on December 10, 1999 and vertical mowing (4.5 mm depth) was performed before and after topdressing in July 2001. Traffic treatments were initiated July 21, 1999.

The fairway trial was seeded on November 10, 1998. It was fertilized with 3.2, 0.4 and 1.3 g m^{-2} of N, P, and K respectively on November 10,1998. Two post-plant fertilizations applied 5.9, 0.8, and 3.4 g m^{-2} of N, P, and K respectively. Fertilization applied (14 times) a total of 34.1, 5.3, and 17.2 g m^{-2} of N, P, and K respectively in 1999; 2.4 g m^{-2} of N in 2000 (once) and 8.0, 2.3, 4.5 g m^{-2} of N, P, and K respectively in 2001(5 times). Mowing was initiated on December 14, 1998 at 15.7 mm and was gradually lowered to 13.5 mm on October 21, 1999 and 10.3 mm on March 23, 2000. Mowing was performed 3 to 4 times per week with clippings removed. Traffic treatments were initiated July 22, 1999.

Wear was applied using a 0.8-m wide wear simulator constructed from a modified walk behind power broom as described by Bonos et al. (4). Compaction treatments were applied using either a 0.6-m wide 432-kg water-filled turf roller or a 0.8-m wide 1,173-kg vibratory pavement roller. Wear and compaction treatment consisted of 2 passes of the wear simulator and/or compaction roller applied twice per week (4 passes per week) from mid-May through September. Once every two weeks, the 1,173-kg vibratory pavement roller was used in replacement of the water-filled roller to apply 2 passes to assure adequate compactive force was applied.

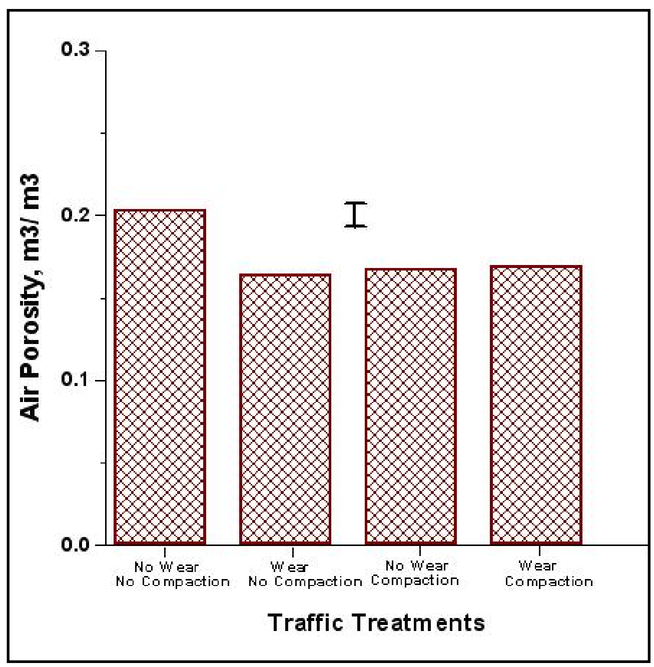


Figure 4. Air porosities of 0- to 51-mm surface depth as affected by traffic on a putting green grown on a sandy loam in 2001.

Source of Variation	Density	Air-filled Porosity†	Capillary Porosity	K_{sat}
Wear	NS	**	NS	NS
Compaction	NS	*	NS	NS
Wear x Compaction	**	***	NS	NS
CV (%)	2.0	4.2	2.8	31.7

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Air-filled porosity was determined by subtraction of capillary porosity (measured as water retention at -10 kPa water potential) from total porosity. Total porosity was calculated from bulk density assuming a particle density of 2.65 Mg m^{-3}.

Table 1. Analysis of variance (ANOVA) table of soil physical properties

Observations, Data Collection, and Analysis

Plots were evaluated in early spring, late spring, summer, and fall for quality during 1999, 2000, and 2001 and in spring and late summer for density using a 1-to-9 scale (1 representing poorest quality turf, 9 the best quality turf, and 5 being the minimally acceptable rating). A line-intersect grid count method (25) provided 209 observations per plot for determining the bentgrass population in spring, summer, and fall of 1999, 2000, and 2001

Four 76-mm diameter undisturbed core samples were randomly taken from the 0- to 51-mm surface soil depth of unseeded subplots of main (traffic) plots in October 2001 for assessment of physical properties. The composition of the turf in these plots was predominantly annual bluegrass. Saturated water conductivity of each core sample was determined from a ½-h flow period after 4-h of constant-head flow (21). Air-filled porosity was determined by subtracting capillary porosity measured at -10 kPa water potential (31) from the calculated total porosity (1).

Data were analyzed using the analysis of variance procedures of SAS (Version 9.1). Soil physical properties data were analyzed using a 2 x 2 factorial arrangement of wear and compaction factors in a randomized complete block design for both trials. All other data were analyzed using a split-plot design with main plots arranged as a 2 x 2 factorial and 15 cultivars as subplots. Turf quality and density ratings were averaged for a given year.

RESULTS

Soil Physical Properties

Putting Green Study

Bulk densities of the surface 0- to 51-mm of the plots were relatively low (Figure 1), which was due to the large organic matter content within the thatch-mat layer, where biomass was accumulated in the form of crowns, roots, and stolons. This organic matter also added resiliency, which limited the damaging effects of compaction from bi-weekly and weekly treatments using 1,173 kg- and 432-kg rollers, respectively. Bulk densities of all traffic plots were higher than the non-traffic plots. Traffic treatments did not affect capillary porosity or K_{sat} (Figures 2 and 3).

Compaction increased bulk density and decreased air-filled porosity of non-wear plots, without affecting wear plots (data not shown). Similarly, wear treatments did not affect bulk density and air-filled porosity on the plots that also received compaction treatments, but increased bulk density on non-compacted plots. It is possi-

Main Effects	Bulk Density	Air-filled† Porosity	Capillary Porosity	K_{sat}
	$Mg\ m^{-3}$	-------------- $m^3\ m^{-3}$	------------	$mm\ h^{-1}$
No Wear	0.97	0.229	0.404	92
Wear	1.07	0.197	0.401	74
No Compaction	0.99	0.239	0.386	126
Compaction	1.04	0.188	0.419	40
<u>Source of Variation</u>				
Wear	***	*	NS	NS
Compaction	**	**	**	**
Wear x Compaction	NS	NS	NS	NS
CV (%)	1.9	7.5	3.6	38.5

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Air-filled porosity was determined by subtraction of capillary porosity (measured as water retention at -10 kPa water potential) from total porosity. Total porosity was calculated from bulk density assuming a particle density of 2.65 $Mg\ m^{-3}$.

Table 2. Soil physical properties of the 0- to 51-mm surface depth as affected by wear and compaction in a fairway trial grown on sandy loam; sampled in October 2001.

ble that the repeated wear thinned out the turf and, as a result, the resiliency of the turf was reduced and allowed compaction of the surface from the rotating flexible paddles on the wear simulator. Bulk density changes were a result of decreased air-filled porosity, yet K_{sat} was not affected, which further illustrated the resiliency of this sand top-dressed turf grown on sandy loam (Figures 3 and 4).

<u>*Fairway Study*</u>

The surface layer of 0- to 51-mm in the fairway trial indicated lower bulk densities than the putting green trial (Table 2) due to the sand topdressing practice that added sand (high particle density material) to the thatch-mat layer of the putting green. Surface bulk density of fairway plots was increased by both compaction and wear treatments (Table 2). Air -filled porosity and K_{sat} levels were higher than the soil green trial especially under the no traffic and wear-only treatment plots. Compaction decreased air-filled porosity and increased capillary porosity, while wear only decreased air-filled porosity (Table 2) compared to plots receiving no non-traffic treatments. This structural change at the surface of wear plots was apparently not large enough to reduce K_{sat}, whereas compaction treatments reduced K_{sat} (Table 2). Despite lower bulk densities, other physical properties in the fairway trial indicated that the fairway turf cover was not as resilient to traffic as turf cover in the putting green that received sand topdressing.

Cultivar Responses to Traffic

While traffic and cultivar effects explained much of the variation in turf responses, significant interactions were observed. Interactions involving the cultivars indicated that the cultivars that were affected under wear and/or compaction levels were more noteworthy than any change in the ranking of cultivars under wear and compaction. Thus, discussion of the interactive effects involving the cultivar factor on the effect of wear and/or compaction factors within cultivars is appropriate.

Source of Variation	Putting Green Trial: Turf Quality† 2000	Putting Green Trial: Turf Quality† 2001	Putting Green Trial: Turf Density‡ 2000	Putting Green Trial: Turf Density‡ 2001	Fairway Trial: Turf Quality§ 2000	Fairway Trial: Turf Quality§ 2001	Fairway Trial: Turf Density 2000	Fairway Trial: Turf Density 2001
Wear	***	***	***	***	***	**	***	***
Compaction	*	*	NS	***	***	*	**	***
Wear x Compaction	NS	***	NS	**	*	NS	NS	NS
Cultivar	***	***	***	***	***	***	***	***
Wear x Cultivar	*	NS	**	NS	NS	**	**	**
Compaction x Cultivar	***	*	NS	NS	**	NS	*	**
Wear x Compaction x Cultivar	**	NS	NS	NS	*	*	*	**
CV (%)	8.6	10.2	9.5	10.4	7.2	8.4	8.1	8.5

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Number of observations for average annual quality was 5 and 4 in 2000 and 2001, respectively.
‡ Number of observations for average annual density was 2 in 2000 and 2001, respectively.
§ Number of observations for average annual quality was 6 and 5 in 2000 and 2001, respectively. Number of observations for average annual density was 2 in 2000 and 2001, respectively.

Table 3. ANOVA table of average annual turf quality and average turf density as affected by wear, compaction and cultivar in putting green and fairway trials grown on a sandy loam in 2000 and 2001.

Bentgrass Cultivar	2000 Turf Quality: No Wear No Comp	2000 Turf Quality: No Wear Comp	2000 Turf Quality: Wear No Comp	2000 Turf Quality: Wear Comp	2001 Turf Quality: No Comp	2001 Turf Quality: Comp
	1-to-9 scale†					
Vesper‡	8.2	8.1	7.3	7.4	7.7	7.5
7001‡	7.5	7.0	6.9	7.0	7.2	7.0
SR 7200‡	7.5	7.5	7.3	6.4	6.5	6.0
Penn A-4	8.5	8.5	7.6	7.8	6.8	7.0
Penn G-2	8.3	8.7	7.2	7.4	6.1	6.5
Century	7.5	7.6	6.6	6.6	6.1	5.7
L-93	7.3	6.6	6.3	5.6	5.4	5.0
SR 1119	6.5	6.8	5.4	6.0	4.6	4.7
Providence	6.8	5.5	5.0	4.0	4.6	3.7
Southshore	5.8	5.3	5.6	5.0	4.1	3.7
SR 1020	5.6	6.0	4.3	4.9	3.9	4.1
Putter	5.3	4.9	3.8	3.8	4.2	3.9
Penneagle	5.1	4.5	4.3	4.0	3.4	3.3
Pennlinks	4.5	4.5	3.6	2.9	3.2	3.0
Penncross	4.2	3.9	3.1	3.4	2.8	2.8
$LSD_{0.05}$	0.7				0.8	

† 9 represents the best turf quality and 5 represents the minimally acceptable rating.
‡ Denotes velvet bentgrass cultivar; all others are creeping bentgrass.

Table 4. Interaction effects of wear x compaction (comp) x cultivar in 2000 and compaction x cultivar in 2001 on average annual turf quality in a putting green trial grown on a sandy loam

Wear x Compaction: Wear Level	Compaction Level	Turf Quality	Turf Density
		1 to 9 scale†	
No Wear	No Compaction	5.6	5.9
No Wear	Compaction	5.6	5.7
Wear	No Compaction	4.6	5.1
Wear	Compaction	4.2	4.4
LSD $_{0.05}$		0.2	0.3

† 9 represents the best turf characteristic and 5 represents the minimally acceptable rating.

Table 5. Interaction effects of wear x compaction on average annual turf quality and average turf density in a putting green trial grown on a sandy loam in 2001.

Putting Green Study

Generally, turf quality decreased due to wear treatment but response to compaction treatment was relatively small in 2000 (Table 4). Wear decreased turf quality of nearly all cultivars at one or both levels of compaction except '7001', which did not respond to wear in 2000 (Table 4). Additionally, wear did not affect turf quality of 'SR 7200' and 'Southshore' in uncompacted plots and 'Penncross' in compacted plots. Compaction did not affect turf quality of most cultivars, however compaction decreased turf quality of 'Providence' in no-wear plots and 'SR 7200', 'Providence', and 'Southshore' in plots receiving wear treatments.

Bentgrass Cultivar	2000 Turf Density, Wear x Cultivar: No Wear	Wear	2001 Turf Density, Cultivar Main Effect
	1-to-9 scale†		
Vesper ‡	8.6	7.7	7.9
7001‡	7.9	7.3	7.2
SR 7200‡	8.4	7.8	6.8
Penn A-4	8.1	7.6	7.2
Penn G-2	8.5	7.4	6.7
Century	7.7	7.0	6.3
L-93	6.9	5.9	5.5
SR 1119	6.5	5.9	5.2
Providence	6.4	4.4	4.3
Southshore	5.8	5.6	4.3
SR 1020	5.9	4.3	4.0
Putter	5.4	4.5	4.1
Penneagle	5.1	4.1	3.6
Pennlinks	4.7	3.4	3.0
Penncross	4.6	3.3	3.0
LSD $_{0.05}$	0.8		0.4

† 9 represents the best average turf density and 5 represents the minimally acceptable rating.
‡ Denotes velvet bentgrass cultivar; all others are creeping bentgrass.

Table 6. Interaction effects of wear x cultivar in 2000 and cultivar main effect in 2001 on average turf density in a putting green trial grown on a sandy loam.

Bentgrass Cultivar	2000 Turf Quality No Wear No Comp	No Wear Comp	Wear No Comp	Wear Comp	2001 Turf Quality No Wear No Comp	No Wear Comp	Wear No Comp	Wear Comp
	-----------------	-----------------	-----------------	-----------------	1-to-9 scale†	-----------------	-----------------	-----------------
7001‡	8.8	8.5	8.6	6.9	9.0	8.5	8.4	7.1
SR 7200‡	8.1	7.0	7.5	5.9	7.9	6.3	7.2	5.5
Penn A-4	8.4	8.3	7.3	6.6	7.9	7.7	6.3	5.8
Penn G-2	8.5	7.2	7.1	6.3	8.1	6.7	5.9	5.3
Penn G-1	8.3	7.7	7.2	5.7	7.7	7.3	6.1	4.7
Century	6.5	6.2	5.4	4.9	6.7	5.9	5.3	4.5
L-93	7.1	5.9	5.5	4.9	6.9	5.9	5.4	4.2
SR 1119	7.1	6.5	5.8	5.3	6.7	5.9	5.1	4.5
Providence	6.3	4.9	4.5	3.8	5.9	4.6	3.8	3.1
Southshore	5.9	5.8	4.6	4.6	5.8	5.4	4.1	3.9
SR 1020	5.9	5.3	4.8	3.4	5.9	5.3	3.9	2.6
Putter	6.0	6.3	5.1	4.1	6.1	5.4	5.0	3.3
Penneagle	5.4	5.3	4.3	4.0	5.5	5.7	4.1	3.2
Pennlinks	5.0	4.4	4.4	3.6	4.9	4.2	2.9	2.8
Penncross	4.4	4.1	4.4	3.2	4.7	3.9	3.7	2.5
$LSD_{0.05}$	1.0				1.0			

† 9 represents the best average annual turf quality and 5 represents the minimally acceptable rating.

‡ Denotes velvet bentgrass cultivar; all others are creeping bentgrass.

Table 7. Interaction effects of wear x compaction (Comp) x cultivar on average annual turf quality in a fairway trial grown on a sandy loam in 2000 and 2001.

In 2001, compaction decreased turf quality of only 'Providence' (Table 4). Wear decreased turf quality of both compacted and uncompacted plots, whereas compaction only reduced quality in the presence of wear (Table 5). 'Vesper', '7001', and 'Penn A-4' had the best turf quality during the last year of the trial (2001) while 'Penneagle', 'Pennlinks', and 'Penncross' had the poorest turf quality (Table 4). It is notable that velvet bentgrass cultivars had better turf quality than most of the creeping bentgrass cultivars studied regardless of whether they received wear or compaction treatments.

Compaction did not affect turf density in 2000 (Table 3). Wear decreased turf density of all cultivars except '7001', 'SR 7200', and 'Penn A-4' (Table 6). An immediate reduction of turf density in 2000 caused by wear would be expected since wear damage is acute causing immediate thinning of turf while compaction is a chronic stress (9). In 2001 (Table 3), wear continued to decrease turf density regardless of whether plots received compaction or not, while compaction treatments only reduced density in the presence of wear (Table 5).

In 2001, 'Vesper' was the most dense cultivar, followed by '7001' and 'Penn A-4'. 'Pennlinks' and 'Penncross' were the least dense (Table 6). Sifers et al. (29) studied twelve bentgrass cultivars and reported similar observations for shoot density. They noted that 'Penn G-2' had the highest shoot density at 3,547 shoots dm^{-2} and 'Pennlinks' and 'Penncross' had the lowest at 1,353 and 1,369 shoots dm^{-2}, respectively. Beard et al. (3) reported 'Penn G-2' had the second highest density among the thirteen creeping bentgrass cultivars studied while 'Putter', 'Penneagle' and 'Penncross' had the lowest. Our data indicated that cultivar differences in turf density exhibited under non-traffic conditions should also be evident under trafficked conditions.

Bentgrass Cultivar	2000 Turf Density: No Wear No Comp	No Wear Comp	Wear No Comp	Wear Comp	2001 Turf Density: No Wear No Comp	No Wear Comp	Wear No Comp	Wear Comp
	----------------------1-to-9 scale†				----------------------			
7001‡	8.8	8.8	8.7	7.5	9.0	8.3	85 7.3	
SR 7200‡	8.0	7.5	7.3	7.0	8.5	6.7	7.5	6.0
Penn A-4	8.3	8.2	7.5	7.0	8.2	8.1	7.0	5.8
Penn G-2	8.7	7.5	7.0	6.2	8.0	6.5	6.0	5.8
Penn G-1	8.2	7.3	7.2	6.0	8.0	7.2	6.7	4.8
Century	7.5	6.2	5.3	5.7	7.8	6.2	5.5	4.7
L-93	6.8	5.8	5.5	5.3	7.5	5.7	5.2	4.3
SR 1119	6.3	5.8	5.3	5.5	6.7	6.0	5.5	4.3
Providence	6.0	4.7	4.0	3.2	6.3	4.2	3.5	2.8
Southshore	5.7	5.5	4.3	4.8	6.0	5.7	3.8	3.5
SR 1020	6.0	5.0	4.7	3.3	6.5	5.0	3.8	1.8
Putter	5.5	5.3	5.0	3.7	6.0	5.7	4.3	3.2
Penneagle	5.0	4.3	4.2	3.8	5.3	4.5	3.5	3.0
Pennlinks	4.5	3.8	4.3	3.2	4.8	3.7	3.0	2.8
Penncross	3.7	3.5	3.7	2.7	5.0	3.3	3.7	2.7
$LSD_{0.05}$	0.8				1.3			

† 9 represents the best average turf density and 5 represents the minimally acceptable rating.

‡ Denotes velvet bentgrass cultivar; all others are creeping bentgrass.

Table 8. Interaction effects of wear x compaction (comp) x cultivar on average annual turf density in a fairway trial grown on a sandy loam in 2000 and 2001.

Fairway Study

Turf quality response in the fairway trial was more varied than the putting green trial. Also, more cultivars were responsive to the compaction treatment as would be expected based on the greater extent of detrimental soil physical properties responses observed in the fairway trial (Table 2). Wear reduced turf quality of ten cultivars in no-compaction plots and twelve cultivars in compaction plots in 2000. ‘Pennlinks’ and ‘Penncross” were the only cultivars not affected by wear in either compacted or non-compacted plots (Table 7).

Compaction did not alter turf quality of twelve cultivars in no-wear plots and nine cultivars in wear plots during 2000. However compaction decreased turf quality of ‘SR 7200’ in plots receiving wear treatments and those receiving no wear treatments. Wear decreased turf quality of nearly all cultivars in 2001. Only ‘SR 7200’ was not affected at both levels of compaction. Compaction did not alter turf quality of twelve cultivars in no-wear plots and nine cultivars in wear plots in 2001. However, compaction did reduce quality of ‘SR 7200’ at both levels of wear.

Wear reduced turf density of fewer cultivars (nine cultivars in no-compaction plots and seven in compaction plots) in 2000 (Table 8) than observed in the putting green trial (Table 6). Wear reduced density of ‘Penn G-2’, ‘Penn G-1’, ‘Providence’, and ‘SR 1020’ in plots receiving compaction or not, whereas wear did not affect ‘SR 7200’, ‘Pennlinks’, and ‘Penncross’ at both levels of compaction (Table 8).

Compaction decreased turf density of six cultivars in both no-wear and wear plots in 2000. Compaction reduced density of ‘Penn G-1’ and ‘SR 1020’ at both levels of wear. Wear reduced turf density of nine cultivars in no-compaction

Source of Variation	Putting Green Trial July 28, 2000	Putting Green Trial August, 13 2001	Fairway Trial August 7, 2000	Fairway Trial August 22, 2001
Wear	**	***	***	***
Compaction	NS	*	***	***
Wear x Compaction	NS	NS	*	NS
Cultivar	***	***	***	***
Wear x Cultivar	NS	*	*	***
Compaction x Cultivar	NS	*	NS	**
Wear x Compaction x Cultivar	**	*	*	**
CV (%)	2.9	10.1	3.8	5.1

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.

Table 9. ANOVA table of bentgrass populations during mid-season of 2000 and 2001 as affected by wear, compaction and cultivar in putting green and fairway trials grown on a sandy loam.

plots and eleven cultivars in compaction plots in 2001. Cultivars not affected by wear at both levels of compaction were '7001' and 'Penncross'. Compaction decreased turf density of seven cultivars in no-wear plots and only three cultivars in wear plots in 2001. Cultivars affected by compaction at both levels of wear were 'SR 7200' and 'SR 1020'.

Bentgrass Population

Bentgrass population data (Tables 9, 10 and 11) for mid-season were presented because this time represents a key time of the growing-playing season for golf course turf. These data were representative of populations measured at other times of the year. Generally, bentgrass population decreased as the study progressed and annual bluegrass encroached. Decreased bentgrass population was particularly evident for lower-density cultivars, as well as plots that received wear treatment (Tables 10 and 11).

Putting Green Study

The analysis of variance(ANOVA) results of both the putting green trial and the fairway trial are shown in Table 9. Wear decreased bentgrass population of five cultivars in no-compaction plots and seven cultivars in compaction plots measure on July 28, 2000. Wear decreased bentgrass population of 'Penn G-2', 'SR 1020', and 'Pennlinks' at both levels of compaction (Table 10). Compaction decreased bentgrass population of only two cultivars: 'Putter' in no-wear plots and 'SR 7200' in wear plots. Unexpectedly, compaction increased bentgrass population of 'Putter' in wear plots. However, this response was not evident in 2001 (Table 10). Bentgrass populations in 'Vesper', '7001', 'Penn A-4', and 'L-93' did not change regardless of the level of wear or compaction in 2000. And 'Vesper', '7001', and 'Penn A-4' maintained bentgrass populations of 92% or more over all levels of wear and compaction.

Bentgrass populations ranged from 48 to 99% on August 13, 2001 (Table 10). Wear decreased bentgrass population of nine cultivars in no-compaction plots and seven cultivars in compaction plots and wear decreased bentgrass of 'Penn G-2', 'SR 1119', 'Southshore', and 'SR 1020' at both levels of compaction (Table 10). Compaction decreased bentgrass population of only four cultivars: 'Southshore' in no-wear plots and 'SR 1119', 'SR 1020', and 'Penneagle' in wear plots. Interestingly, compaction increased bentgrass population of 'Pennlinks' from 53 to

Bentgrass Cultivar	July 28, 2000				August 13, 2001			
	No Wear No Comp	No Wear Comp	Wear No Comp	Wear Comp	No Wear No Comp	No Wear Comp	Wear No Comp	Wear Comp
	(% cover)†							
Vesper‡	95.7	94.1	94.3	92.6	99.0	96.9	97.7	94.7
7001‡	95.3	95.6	93.5	93.1	99.0	96.7	96.2	93.7
SR 7200‡	94.3	93.3	92.7	89.3	96.7	93.7	92.9	85.2
Penn A-4	95.3	94.6	92.3	93.5	91.5	91.6	79.4	81.2
Penn G-2	95.6	95.6	91.7	90.2	90.3	90.8	75.9	79.8
Century	91.5	93.7	92.7	89.2	86.7	84.6	84.1	73.6
L-93	91.0	90.1	87.9	87.7	81.5	73.4	64.4	69.5
SR 1119	91.9	90.0	82.8	86.5	77.6	71.5	60.4	47.8
Providence	89.2	88.9	86.8	83.3	73.0	76.1	60.9	67.5
Southshore	89.6	91.5	87.4	85.4	81.5	70.7	53.1	55.4
SR 1020	89.5	90.0	84.8	83.3	80.1	70.7	65.0	54.1
Putter	92.7	85.9	85.9	90.7	82.7	74.6	64.7	68.4
Penneagle	89.5	88.6	85.8	83.3	78.0	74.6	68.9	53.1
Pennlinks	90.4	89.6	85.4	84.9	68.3	73.6	53.1	64.4
Penncross	88.8	86.1	86.4	84.1	64.0	66.1	54.1	48.4
$LSD_{0.05}$	3.8				10.7			

† Cover measured as the percent of 209 line-intersect observations of bentgrass (remainder was annual blue grass) over 1.35 m^2 of each plot.
‡ Denotes velvet bentgrass; all others are creeping bentgrass.

Table 10. Interaction effects of wear x compaction (comp) x cultivar on bentgrass populations (% area of plot) in a putting green trial grown on a sandy loam in 2000 and 2001.

64% in wear plots in 2001 (Table 10). However, turf quality and density data did not provide insight to explain this response in ‘Pennlinks’ plots. Moreover, the practical significance of the increased bentgrass population of ‘Pennlinks’ appeared to be limited since the bentgrass population (64%) was low compared to the best performing creeping bentgrass (81% bentgrass for ‘Penn A-4’) at that level of traffic. Bentgrass population in ‘Vesper’ and ‘7001’ plots were 93% or greater and were not significantly affected by the level of wear or compaction.

Beard et al. (3) reported that ‘Penncross’ creeping bentgrass had low shoot density (1,369 shoots dm^{-2}) and was less competitive against annual bluegrass encroachment in established non-trafficked turf compared to ‘Penn G-2’ and ‘Penn A-1’ that had shoot densities above 2,000 shoots dm^{-2}. Cashel et al. (10) found that denser cultivars tolerated traffic stresses on a sand-based rootzone and resisted infestation by annual bluegrass overseeding better than older, less dense cultivars.

Fairway Study

More cultivars in the fairway trial responded to wear and compaction than in the putting green study with respect to bentgrass populations. Wear decreased bentgrass populations of most cultivars measured on August 7, 2000. Only ‘7001’ and ‘SR 7200’ in no-compaction plots and ‘SR 7200’, ‘Penn G-1’, and ‘Pennlink’s in compaction plots did not respond to wear. Compaction decreased bentgrass population of eleven cultivars in no-wear plots and five cultivars in wear plots. Compaction decreased bentgrass population of ‘Penn G-2’, ‘L-93’, ‘Providence’,

Bentgrass Cultivar	August 7, 2000 No Wear No Comp	No Wear Comp	Wear No Comp	Wear Comp	August 22, 2001 No Wear No Comp	No Wear Comp	Wear No Comp	Wear Comp
	(% cover)†							
7001‡	99.2	96.5	96.3	90.1	99.8	99.0	98.1	92.5
SR 7200‡	96.7	91.9	91.4	88.7	99.4	94.7	92.8	82.9
Penn A-4	98.2	93.3	91.4	87.4	99.2	95.7	91.2	82.6
Penn G-2	97.6	87.6	87.8	76.9	97.8	84.8	89.3	72.4
Penn G-1	97.6	93.5	91.2	88.2	98.6	95.2	90.9	79.3
Century	96.2	89.3	86.9	82.0	96.2	89.0	85.0	71.5
L-93	94.1	86.3	83.7	73.7	95.2	82.9	78.3	65.9
SR 1119	93.1	85.3	82.8	77.5	91.4	83.6	73.0	63.9
Providence	92.7	84.5	80.9	73.0	93.1	77.4	74.3	60.9
Southshore	94.6	88.2	79.4	78.5	93.8	83.3	75.4	72.6
SR 1020	92.0	76.9	75.4	70.5	92.3	77.2	74.8	60.9
Putter	95.7	89.0	84.8	80.2	96.5	91.1	81.8	73.7
Penneagle	92.3	86.8	83.9	76.7	92.8	83.7	76.1	63.6
Pennlinks	92.0	80.0	80.7	75.6	87.4	74.0	74.8	68.3
Penncross	91.1	78.5	77.0	73.0	88.0	70.8	72.7	59.2
$LSD_{0.05}$		5.3				6.8		

†Cover measured as the percent of 209 line-intersect observations of bentgrass (remainder was annual bluegrass) over 1.35 m2 of each plot.

‡ Denotes velvet bentgrass; all others are creeping bentgrass.

Table 11. Interaction effects of wear x compaction (comp) x cultivar on bentgrass populations in a fairway trial grown on a sandy loam in 2000 and 2001.

and 'Penneagle' at both levels of wear. While all cultivars decreased in bentgrass population due to some level of wear and/or compaction, by August 7, 2000, bentgrass population did not fall below 90% for '7001', 89% for 'SR 7200', 88% for 'Penn G-1', and 87% for 'Penn A-4'.

Wear decreased bentgrass populations of nearly all cultivars by August 22, 2001 except '7001' and 'SR 7200' in no-compaction plots and '7001' and 'Pennlinks' in compaction plots (Table 11). Compaction decreased bentgrass populations of ten cultivars in no-wear plots and twelve cultivars in wear plots. Compaction decreased bentgrass in eight cultivars regardless of the level of wear: 'Penn G-2', 'Century', 'L-93', 'SR 1119', 'Providence', 'SR 1020', 'Penneagle', and 'Penncross'. '7001' was the only cultivar that did not lose bentgrass population due to compaction at both levels of wear, and maintained a population range of 93 to 99.8% across all traffic treatments. Of the creeping bentgrass cultivars, 'Penn A-4' and 'Penn G-1' maintained the greatest bentgrass population (83 and 79%, respectively) under the most stressful traffic level of wear plus compaction (Table 11).

Acknowledgements

This work was supported by the New Jersey Agricultural Experiment Station, State and Hatch Act funds, Rutgers Center for Turfgrass Science, and other grants and gifts. Additional support was received from the United States Golf Association, New Jersey Turfgrass Foundation, and Golf Course Superintendents Association of New Jersey.

Literature Cited

1. American Society for Testing and Materials. 1997. Standard test method for saturated hydraulic conductivity, water retention, porosity, particle

density, and bulk density of putting green and sports turf root zones. Natural Playing Surfaces Subcommittee F08.64, ASTM Sports Equipment and Facilities Committee F-8. ASTM Standard F1815-97. ASTM, West Conshohocken, PA. (TGIF Record 96236)

2. Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Englewood Cliffs, NJ. (TGIF Record 294)

3. Beard, J. B., P. Croce, M. Mocioni, A. DeLuca, and M. Volterrani. 2001. The comparative competitive ability of thirteen *Agrostis stolonifera* cultivars to *Poa annua*. *Int. Turfgrass Soc. Res. J.* 9:828-831. (TGIF Record 74368)

4. Bonos, S. A., E. Watkins, J.A. Honig, M. Sosa, T. Molnar, J.A. Murphy, and W.A. Meyer. 2001. Breeding cool-season turfgrasses for wear tolerance using a wear simulator. *Int. Turfgrass Soc. Res.* J. 9:137-145. (TGIF Record 74249)

5. Bonos, S. A., J. A. Murphy, W.A. Meyer, W.K. Dickson, M.E. Secks, J.B. Clark, D. Smith, J. Honig, and B.B. Clarke. 1996. Performance of bentgrass cultivars and selections in New Jersey turf trials. Pages 21-33. *In* A.B. Gould (ed.) 1996 Rutgers Turfgrass Proceedings. Atlantic City, NJ. Dec. 10-12, 1996. (TGIF Record 110488)

6. Brilman, L.A., and W.A. Meyer. 2000. Velvet bentgrass: Rediscovering a misunderstood turfgrass. *Golf Course Management* 68(10): 70-75. (TGIF Record 68883)

7. Canaway, P.M. 1981. Wear tolerance of turfgrass species. *J. Sports Turf Res. Inst.* 57:65-83. (TGIF Record 2280)

8. Carrow, R.N. 1980. Influence of soil compaction on three turfgrass species. *Agron. J.* 72:1038-1042. (TGIF Record 537)

9. Carrow, R.N., and A.M. Petrovic. 1992. Effects of traffic on turfgrass. Pages 285-330. *In* D.V. Waddington et al. (eds.) Turfgrass. Agron. Monogr. 32. ASA, CSSA, and SSSA, Madison, WI (TGIF Record 26027)

10. Cashel R.H., H. Samaranayake, T. J. Lawson, J.A. Honig, and J. A. Murphy. 2005. Traffic tolerance of bentgrass cultivars grown on a sand-based root zone. *Int. Turfgrass Soc. Res. J.* 10:531-537. (TGIF Record 105437)

11. Christians N. 2004. Fundamentals of turfgrass management. 2nd edition. John Wiley & Sons, Hoboken, NJ. (TGIF Record 91849)

12. Croce P., M. Mocioni, and J.B. Beard. 199p. *Agrostis* cultivar characterizations for closely mowed putting greens in Mediterranean climate. *Science and Golf*, E&SN Spoon, London, England, UK, 3:668-678. (TGIF Record 60688)

13. Evans, G.E. 1988. Tolerance of selected bluegrass and fescue taxa to stimulated human foot traffic. *J. Environ. Hort.* 6(1):10-14 (TGIF Record 136921)

14. Fushtey, S.G., D.K. Taylor, and D. Fairey. 1983. The effect of wear stress on survival of turfgrass in pure stands and in mixtures. *Can. J. Plant Sci.* 63:317-322. (TGIF Record 4371)

15. Gore, A. J. P., R. Cox, and T.M. Davies. 1979. Wear tolerance of turfgrass mixtures. *J. Sports Turf Res. Inst.* 55:45-68. (TGIF Record 2260)

16. Greenfield, I. 1962. Turf culture. Leonard Hill, London. (TGIF Record 268)

17. Green Section Staff. 1993. USGA recommendations for a method of putting green construction. *USGA Green Section Record* 31(2):1-3. (TGIF Record 26681)

18. Grime J. P., and R. Hunt. 1975. Relative growth-rate: its range and adaptive significance in a local flora. *J. Ecol.* 63:393-422. (TGIF Record 6858)

19. Honig, J., J. A. Murphy, W. K. Dickson, M. E.

Secks, and J. B. Clarke. 1995. Performance of bentgrass cultivars and selections in New Jersey turf trials. 1995 Rutgers Turfgrass Proceedings. 27:39-48. (TGIF Record 101255)

20. Howe, C.D., and R.W. Snaydon. 1986. Factors affecting the performance of seedlings and ramets of invading grasses in an established ryegrass sward. *J. Appl. Ecol.* 23:139-146. (TGIF Record 8035)

21. Klute, A., and C. Dirksen. 1986. Hydraulic conductivity and diffusivity: Laboratory Methods. *In* A. Klute (ed.) Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. ASA and SSSA, Madison, WI.

22. Law, R. 1981. The dynamics of a colonizing population of *Poa annua*. *Ecology* 62:1267-1277. (TGIF Record 5741)

23. Lush, W.M. 1988. Biology of *Poa annua* in a temperate zone golf putting green (*Agrostis stolonifera*/*Poa annua)* i. The above ground population. *J. Applied Ecology* 25: 977-988. (TGIF Record 13992)

24. Morrish, R.H., and C.M. Harrison. 1948. The establishment and comparative wear resistance of various grasses and grass legume mixtures to vehicular traffic. *J. Amer. Soc. Agron.* 40:168-179. (TGIF Record 13015)

25. Murphy J. A., H. Samaranayake, T. J. Lawson, J. A. Honig, and S. Hart. 2005. Seeding date and cultivar impact on establishment of bentgrass in soil containing annual bluegrass seed. *Int. Turfgrass Soc. Res. J.* 10:410-415. (TGIF Record 105416)

26. National Turfgrass Evaluation Program. 2006. National bentgrass (putting green) test-2003 [Online]. Available at www.ntep.org/reports/bt03g/bt03g_06-3/bt03g_06-3.htm (Verified 7 January 2005). (TGIF Record 111934)

27. Newell, A. J., F. M. E. Crossley, J. C. Hartwoods, C. E. Richards, and A. D. Wood. 1997. STRI report to turfgrass breeders 1997. Sports Turf Research Institute, Bingley, West Yorkshire, U.K. (TGIF Record 138460)

28. Shearman, R.C., and J. B. Beard. 1975. Turfgrass wear tolerance mechanisms. I. Wear tolerance of seven turfgrass species and quantitative methods for determining turfgrass wear injury. *Agron. J.* 67:208-211. (TGIF Record 870)

29. Sifers S.I., J. B. Beard, and M. L. Fraser. 2001. Botanical comparisons of twelve *Agrostis* cultivars in a warm-humid climate. *Int. Turfgrass Soc. Res. J.* 9:213-217. (TGIF Record 74293)

30. Sprague, H. B., and G .W. Burton. 1937. Annual bluegrass (*Poa annua* L.) and its requirements for growth. N. J. Agr. Exp. Sta. Bul. 630. (TGIF Record 16970)

31. Startsev, A.D., and D.H. McNabb. 2001. Skidder traffic effects on water retention, pore-size distribution, and van Genuchten parameters of boreal forest soils. *Soil Sci. Soc. Am. J.* 65:224-231.

32. Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics: A biometrical approach. 2nd ed. McGraw-Hill, New York.

33. Sun, D., and M. J. Liddle. 1993. Plant morphological characteristics and resistance to simulated trampling. *Environ. Management* 17:511-521. (TGIF Record 53611)

34. Trenholm L.E., R.N. Carrow, and R.R. Duncan. 2000. Mechanisms of wear tolerance in seashore paspalum and bermudagrass. *Crop Sci.* 40:1350-1357. (TGIF Record 69365)

35. Wells, G. J. 1974. The biology of *Poa annua* and its significance in grassland. *Herbage Abstracts* 44:385-391. (TGIF Record 5811)