July 2005

The Effects Of Reinforcement Inclusions On Wear Tolerance, Playing Quality And Physical Properties In A Silt Loam And Sand Rootzone Matrix

William M. Dest
University of Connecticut Department of Plant Science

Karl Guillard
University of Connecticut Department of Plant Science, karl.guillard@uconn.edu

Scott Ebdon
University of Massachusetts Amherst Department of Plant and Soil Science

THE EFFECTS OF REINFORCEMENT INCLUSIONS ON WEAR TOLERANCE, PLAYING QUALITY AND PHYSICAL PROPERTIES IN A SILT LOAM AND SAND ROOTZONE MATRIX

William M. Dest*, Karl Guillard and Scott Ebdon

ABSTRACT

Reinforcement inclusions have been advocated to alleviate wear, compaction, and unstable surfaces in sports fields, but little research on the effects of these materials has been conducted in the USA. Experiments were established on a native silt loam and a sand rootzone matrix, seeded with a Kentucky bluegrass (*Poa pratensis* L.) blend, at the Joseph Troll Turf Research Center, University of Massachusetts, Amherst, USA to determine the effects of reinforcement inclusions on wear, surface hardness, traction, ball roll, ball bounce resilience, water infiltration rate, soil bulk density, air porosity, total porosity, and root weights. Three types of reinforcement inclusions (Sportgrass, Netlon, Turfgrids) were tested along with a non-reinforced control in a three year study. The treatments were set out in a randomized complete block design with four replications in both soils. No inclusion provided less wear or greater infiltration or air-filled porosity relative to the control. Reinforcement inclusions showed significant differences, however, in surface hardness, traction, and ball roll relative to the control, although this varied with the time of year. Infiltration rates, air-filled porosity, total pore space, bulk density, hardness, traction, ball roll, and ball rebound were greater on the sand rootzone than on the silt loam. Significant correlations were present between soil bulk density, surface hardness, traction, and ball roll. Based on our study, the use of reinforcement inclusions to provide better wear tolerance for sand or native soil athletic fields is not warranted. Certain playing surface characteristics, however, may be slightly improved with the use of reinforcement inclusions. The use of sands for sports surfaces is justified based upon the improvement in playing quality characteristics and soil physical properties important to a good playing surface.

Keywords

air porosity, ball roll, hardness, infiltration, root weights, traction

INTRODUCTION

Turfgrass wear, soil compaction, and an unstable surface are recurring problems on natural grass sports fields. Sand based construction techniques for building sports fields have been developed to alleviate some of the soil compaction resulting from continued trampling and to promote better drainage and air movement into and through the soil profile. One of the first methods developed using sands was the USGA Green Section method with detailed specifications as to particle size, hydraulic conductivity under saturated flow, and pore space distribution (Ferguson *et al.*, 1960 and Ferguson, 1965). Sand construction methods have also been found to sustain more usage before losing their grass cover compared to construction using natural soils such as sandy loams (Baker and Gibbs, 1989). However, particle stability remains a problem on sand rootzone constructed fields particularly when vegetative cover is worn away through continued use. Furthermore, fields built from natural soils (sandy loams, loams, silt loams, etc.) will have the same problem occurring when soil moisture is near or above field capacity. This especially takes place at the latter part of the playing season in the fall when precipitation exceeds evapotranspiration.

Adams and Gibbs (1994) describe the three types of synthetic reinforcement inclusions as 1) intact fabrics or carpets, 2) mesh fragments, and 3) individual fibers. These materials have shown promise in some situations in providing a stable playing surface, increasing wear tolerance of sports fields, and improving the playing performance of the surface. However, the materials are largely used in fields built using sand constructed techniques.

Adams and Gibbs (1989) reported the benefit of VHAF, a needlepunched-geotextile fabric, in providing stability and traction on sand constructed fields where the vegetative cover was worn away. Smaller divot openings and an increase in turf recovery were noted using interlocking mesh elements incorporated into a sand rootzone compared with the control by Beard and Sifers (1990). However, they found no difference in ball rebound, and traction values were inconsistent between treatments on a Tifway bermudagrass [*Cynodon dactylon* (L.) Pers. x *C. transvaalenis* Burtt Davy] turf. Canaway (1994) reported an increase in traction and hardness and

William M. Dest and Karl Guillard, Department of Plant Science, University of Connecticut, 1376 Storrs Road, Unit-4067, Storrs, CT 06269-4067, USA. Scott Ebdon, Department of Plant and Soil Science, University of Massachusetts, Amherst, MA 01003-0410, USA. *Corresponding author: profdest@aol.com

in water infiltration rates by increasing the amount of mesh element inclusions in a sand. A significant increase in air-filled and total porosity with a subsequent decrease in bulk density by the incorporation of mesh elements in a sand compared with a control was shown in a laboratory and field study by Richards (1994). Baker and Richards (1995) found in a laboratory study that the incorporation of fibers in a sand produced greater total and air-filled porosity as fiber content increased. Baker and Richards (1995) further reported an increase in traction, hardness, and ball rebound in a field trial on sand with increased fiber content thereby supporting a more stable surface. However, they reported no effect on ground cover from the fibers relative to the control (without fibers).

Although most studies utilizing reinforcement inclusions have been in sands, a few studies have been conducted on native soils (Baker *et al.*, 1988; McNitt and Landschoot, 2001). Baker *et al.* (1988) using five reinforcement materials in a sandy loam and sand carpet rootzone found better overall wear and traction on the sandy loam with most of the reinforcement materials, while there was very little effect from these materials used in the sand rootzone when compared with sand rootzones without the inclusions. However, the surface of the sandy loam was reported to be unacceptably soft when it was excessively wet regardless of the reinforcement materials, whereas the sand rootzone surface was slightly harder with the reinforcement materials than sand by itself. Baker *et al.* (1988) found ball rebound characteristics improved on the sandy loam soil in four of five reinforcing materials in wet conditions, with ball rebound within acceptable limits in the sand carpet rootzone regardless of whether reinforcement materials were used. A significant difference in ball roll occurred only once during the two year study due to reinforcement materials. McNitt and Landschoot (2001) found limited benefits from reinforcement inclusions (Sportgrass, Turfgrids, and DuPont Shredded Carpet) relative to the control under three wear treatments that included a non-wear treatment on a silt loam. They assessed turf density, surface hardness and traction, water infiltration rates, soil moisture content, and soil bulk density. Differences in damage from wear treatments across all inclusion treatments were negligible compared with the control. Sportgrass provided the best density of the four treatments but on only one occasion was it better than the control.

The Baker *et al.* (1988) study indicates that reinforcement inclusions may be of greater benefit to improving the playing surface of natural soils of which a majority of sports fields are constructed. Although McNitt and Landschoot (2001) were the first to assess and report these materials in a native soil for athletic field use in the United States, no comparative study of reinforcement inclusions on the difference in their effect on a native soil and sand rootzone has been done here.

The objective of our study was to investigate the effects of three synthetic reinforcement inclusions in a silt loam and a sand rootzone to compare the effects of these materials on the two soils as to: 1) wear tolerance of a cool season turf used for sports fields, 2) surface playing quality, and 3) their influence on soil physical properties.

MATERIALS AND METHODS

A field experiment was conducted at the Joseph Troll Turf Research Center, University of Massachusetts, Amherst, USA over a three year period. Experiments were established in two soil types (a native silt loam (coarse-silty mixed, nonacid, mesic Typic Udifluvents) and a sand rootzone). The silt loam had a sand, slit, clay composition of 244, 666, and 90 g kg^{-1}, respectively, with an organic matter content of 51.9 g kg^{-1}. The sand rootzone had a sand, silt, clay composition of 975, 22, and 3.0 g kg^{-1}, respectively, with an organic matter content of 13.5 g kg^{-1}.

Three types of reinforcement inclusions were tested in each soil with a control (no reinforcement inclusions). The reinforcement materials were an intact fabric Sportgrass (Sportgrass Inc., McLean, Virginia, USA) comprising a polypropylene woven backing with 37 mm polypropylene fibers tufted into the backing, Netlon (Netlon Limited, Blackburn, UK) which is 50 x 100 mm rectangular polypropylene grids with ribs protruding from the edges and Turfgrids (Stabilizer Solutions, Inc., Phoenix, Arizona, USA) which are root hair like 37 mm long polypropylene fibers that open to form a netlike structure when mixed with soil. Treatments were set out in a randomized complete block design with four replications on each soil. Plot size was 1.8 x 7.3 m.

A wooden framework was constructed to border the plots. The Netlon was mixed with the soils offsite with a bucket loader to achieve 0.74 kg m^{-2} of Netlon and placed to a 152 mm depth for each plot. The Turfgrids were incorporated at 0.68 kg m^{-2} to a 152 mm depth with a rototiller. Thorough mixing was accomplished by removing 76 mm of the soils for each plot, mixing half the amount of Turfgrids into the bottom 76 mm of soil with the rototiller, returning the upper 76 mm of soil and incorporating the remaining Turfgrids into the top 76 mm. The Sportgrass was cut to fit the plots, stapled and then topdressed with a sand meeting USGA specifications (USGA Green Section Staff, 1993) and brushed into the fibers. The sand was topdressed in increments and brushed in until only 6 mm of the fibers were showing. The wooden frames were then removed. The plots were fertilized with 54, 42 and 50 kg ha^{-1} of N, P and K respectively and then sown on 17 Sept. 1997 with 'Eclipse', 'Touchdown' and 'Impact' Kentucky bluegrass cultivars at 90 kg ha^{-1}.

The plots were established through 1998. Nitrogen, P and K were applied in six applications over the 1998 growing season to supply a total of 312, 95, and 213 kg ha^{-1}, respectively, on the sand rootzone. The silt loam plots received 205, 81 and 162 kg ha^{-1} of N, P and K, respectively, over the same growing season. Nitrogen was applied at 214 kg ha^{-1} to both rootzones in four applications over the growing season in the years 1999, 2000 and 2001. Phosphorus was applied at 19, 13 and 3 kg ha^{-1} and K at 97, 138 and 81 kg ha^{-1} to both rootzones in 1999, 2000 and 2001 respectively. The plots were mowed at a 32 mm cutting height on a weekly to twice weekly schedule depending upon the season and growth rate. Grass clippings were returned. The plots were irrigated as required to maintain active growth.

Wear was simulated using a differential slip wear machine (Canaway, 1976) fitted with football cleats. Wear treatments began in August 1999. Wear was imposed from late August through mid-December in 1999, 2000 and 2001. Plots received wear on Tuesday and Thursday each week irrespective of the weather. Three passes were made over the plots each time wear was imposed.

Treatments were assessed for 1) turf properties (wear, recuperative potential, and root weights), 2) soil physical properties (water infiltration, bulk density, air-filled porosity, and total porosity), and 3) player-to-surface and ball-to-surface properties (surface hardness, traction, ball roll, and ball bounce resilience).

Wear and recuperative potential were rated visually on a scale of 1 to 9 in October, November, and December of each year. A rating of 1 indicated no wear and 9 a complete loss of ground cover. Ratings of less than 5 indicated leaf injury with loss of color and a rating of 5 or greater indicated leaf injury and loss of density (thinning). Ratings for recovery were taken in the spring following the previous fall wear in May and June. A rating of 1 indicated 0 to 20% of the plot recovered and a 9 rating indicated 91 to 100% recovery.

At the termination of the study, 6 cores (3.1 cm^2 each) were taken to a depth of 15 cm to measure root weights. The cores were placed on a screen and the soil washed from the cores. The reinforcement materials and aerial portion of the plants were removed by hand after the soil was washed from the roots. The roots were dried at 70° C until a constant weight was obtained. The roots were weighed and then ashed at 600° C for 2 hrs. The ash weight was subtracted from the oven dry weight to obtain the weight of the roots.

Water infiltration was measured using double ring infiltrometers (Bertrand, 1965). The inside and outside rings were 305 mm and 610 mm, respectively. The rings were inserted 25 mm into the ground with measurements taken from the inside ring. The inside ring was filled to 100 mm and the level of drop inside the cylinder measured at intervals and then refilled to the 100 mm level after each interval. Infiltration was recorded once the rate became constant over three measurements. In no instance between intervals was the water allowed to drop below 50 mm. Measurements were made in the summer, 1999 before wear was imposed on the plots, at the end of September 2000 and in June and October, 2001.

At the termination of the study, two undisturbed cores 53 mm in diameter by 30 mm in length were obtained with a brass cylinder fitted inside a metal tube from each plot for determining bulk density (Blake, 1965), total porosity (Vomocil, 1965) and air-filled porosity (Vomocil, 1965; ASTM F1815-97, 1999). Thatch and soil were removed to 38 mm below the surface before inserting the metal tube with the brass cylinder. This included removing a section of the Sportgrass just below the backing, so that the core samples could be obtained. Air-filled porosity values for the silt loam were determined at -10 kPa and at -3 kPa for the sand rootzone.

Surface hardness was measured using a Clegg Impact Soil Tester (Clegg, 1976). An accelerometer was fastened to a 2.25 kg missile dropped from a height of 300 mm with the peak deceleration measured in gravities (Gmax). Measures were taken in the late spring and fall of 1999, 2000, and 2001. Four readings were made per plot each time measurements were taken.

Traction was measured by a device described by Canaway and Bell (1986). The device comprised a 150 mm steel disc with six football studs space at intervals around the disc. The disc was weighted with 34 kg and dropped from a 152 mm height so that the studs fully penetrated the surface. The torque required for the studs to tear the surface was measured and is reported in N m. Four measurements were taken in each plot in the late spring and fall in each of the three years.

Ball roll values for the different treatments were determined by releasing a Diadora FIFA-approved soccer ball inflated to 70 kPa down a 45° inclined ramp (Bell and Holmes, 1988; British Standard, 1989). The ball was released from a height of 1 m and the distance measured from where the ball first met the surface to where it came to rest. Three readings were made in one direction and then repeated in the opposite direction in each plot. Measurements were made in the fall, 1999 and in late spring and fall of 2000 and 2001.

Ball rebound resilience was measured by releasing a Diadora FIFA-approved soccer ball inflated to 70 kPa from a height of 3 m and then measuring its rebound height (Bell and Holmes, 1988; British Standard, 1989). Four readings were taken in each plot. Measurements were made in the fall of 1999 and 2000 and in the late spring and fall of 2001. The results are reported as a ratio of the rebound height over the release height expressed as a percentage.

The data were subjected to the ANOVA procedure of SAS (The SAS Institute, 1990) using the combined analysis of variance across sites (soils). Tukey's Honestly Significant Difference test was used to separate means when the *F*-test was significant for treatment effects. Correlation coefficients were determined for the relationships of bulk density to surface hardness, traction, and ball roll, and the relationships of air porosity to infiltration and root weights.

Table 1. The mean wear ratings for the main effects of reinforcement inclusions and soils on turfgrass wear ratings in 1999, 2000, and 2001.

	1999			2000			2001		
	Oct.	Nov.	Dec.	Oct.	Nov.	Dec.	Oct.	Nov.	Dec.
	Wear ratings†								
Inclusions									
Sportgrass	3.9	5.1	5.8	3.5a‡	4.8a	6.8a	6.1a	7.3a	8.0a
Turfgrids	3.0	4.6	5.6	2.3b	2.5b	5.0b	4.1b	5.1b	6.0b
Netlon	2.6	4.3	5.6	1.8b	2.4b	5.8ab	4.1b	4.6b	6.0b
Control	2.6	5.0	6.3	2.1b	2.1b	5.1b	4.3b	4.8b	5.3b
Soils									
Sand rootzone	3.6	4.8	5.4	3.3	3.8	5.4	3.3	5.1	6.4
Silt loam	2.5	4.7	6.2	1.5	2.1	5.9	6.1	5.8	6.2
F test									
Inclusion (I)	NS	NS	NS	**	**	*	**	**	**
Soils (S)	**	NS	NS	**	**	NS	**	**	NS
I x S	NS	NS	**	*	NS	NS	NS	NS	NS
CV%	31.1	31.4	18.0	15.2	13.8	12.7	23.1	30.3	18.3

*,**,NS Significant at $P < 0.05$, 0.01, and not significant ($P > 0.05$), respectively.

† Visual estimates of wear 1 = no wear; 9 = complete loss of ground cover. A rating of less than 5 indicates leaf injury with loss of color; 5 or greater indicates leaf injury and loss of density.

‡ Means within a column for inclusions followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Turfgrass Wear and Recovery

Fall turfgrass wear ratings for 1999, 2000, and 2001 are shown in Table 1. None of the reinforcement inclusions resulted in less wear than the control across the two soils, with the exception of December 1999 (Fig. 1). Sportgrass plots had significantly less damage from wear than the control in the silt loam, but there was no difference between the two treatments in the sand rootzone for the last ratings taken in December 1999. Wear on the Sportgrass was significantly greater on the sand rootzone than the Netlon treatment (Fig. 1). In October 2000 (Fig. 2), both control and Netlon had significantly less wear than Sportgrass in the sand rootzone plots. There was no effect of the inclusions in the silt loam.

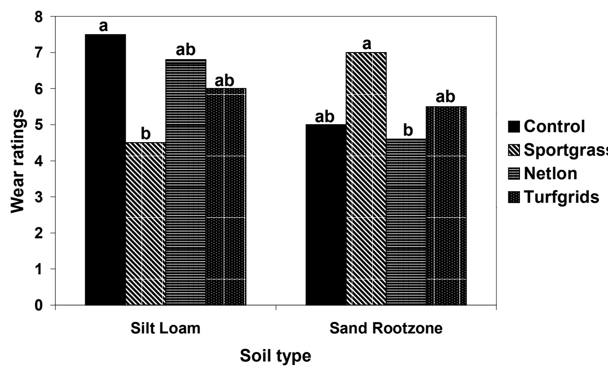

Figure 1. Effect of reinforcement inclusions x soil on wear in December 1999. Visual estimates of wear 1 = no wear; 9 = complete loss of ground cover. A rating of less than 5 indicates leaf injury with loss of color; 5 or greater indicates leaf injury and loss of density. Means for inclusions within a soil followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($\alpha = 0.05$).

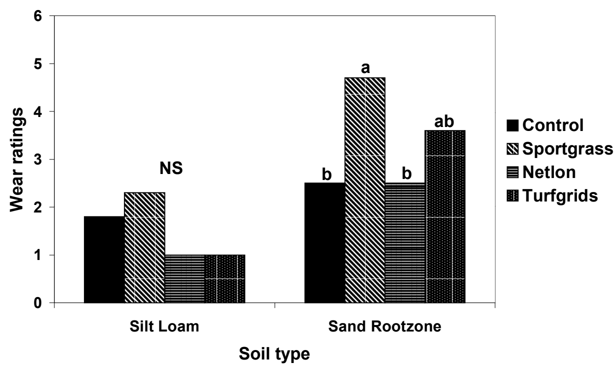

Figure 2. Effect of reinforcement inclusions x soil on wear in October 2000. Visual estimates of wear 1 = no wear; 9 = complete loss of ground cover. A rating of less than 5 indicates leaf injury with loss of color; 5 or greater indicates leaf injury and loss of density. Means for inclusions within a soil followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($\alpha = 0.05$).

All the treatments showed a loss in turf density (wear ratings 5 or greater) as the fall season advanced into December of each year (Table 1). There was significantly greater wear on the Sportgrass than all the treatments in November and December 2000 except between Sportgrass and Netlon at the December rating. This trend continued from October through December 2001. McNitt and Landschoot (2001) reported that Sportgrass provided better wear tolerance than several other treatments including Turfgrids in two out of five dates that ratings were taken. However, Sportgrass gave better wear only on one out of five dates relative to the control. The study was carried out on a silt loam. The only date that Sportgrass gave better wear than the control in our study was on the silt loam in December 1999. Baker and Richards (1995) found little difference on ground cover using a fibre-reinforcement inclusion on a sand rootzone in which significant differences in fibre inclusions were found only on two out of 10 dates when ratings were taken.

The silt loam provided significantly better wear than the sand rootzone soil in early to mid fall in 1999 and 2000 (Table 1) in three out of the six dates ratings were collected. However, the opposite occurred in 2001 when the turf growing on the silt loam was showing significantly more wear than the sand rootzone in October and November. This may be attributed to the ingress of annual meadow-grass (*Poa annua* L.) into the silt loam plots. The silt loam plots comprised 42% annual meadow-grass at the beginning of imposing wear in August 2001 (data not shown). The sand rootzone had less than 3% annual meadow-grass. There was no treatment by soil interaction for annual meadow-grass infestation. Averaged across soils, the Sportgrass treatment had significantly less annual meadow-grass (17%) than the control (29%). However, even this did not account for the Sportgrass having significantly more wear than the other treatments in 2001. There was no significant difference in wear between soils at the last rating in all three years.

Table 2. The mean recovery ratings for the main effects of reinforcement inclusions and soils in 2000, 2001, and 2002.

	2000		2001		2002	
	May	June	May	June	May	June
	Recovery ratings†					
Inclusions						
Sportgrass	5.6	6.8	5.8b‡	8.0b	6.6	8.1
Turfgrids	6.5	7.4	6.8ab	9.0a	6.6	8.1
Netlon	6.4	7.6	7.3a	8.9a	7.0	7.8
Control	7.4	7.6	7.3a	8.4ab	6.3	7.6
Soils						
Sand rootzone	6.0	6.4	4.9	8.2	5.8	7.3
Silt loam	6.9	8.3	8.6	8.9	7.4	8.6
F test						
Inclusion (I)	NS	NS	**	**	NS	NS
Soils (S)	NS	**	**	NS	NS	NS
I x S	NS	NS	NS	**	NS	NS
CV%	19.1	17.1	10.1	5.6	11.6	8.7

† Recovery ratings 1 = 0-20% vegetative cover; 9 = 91-100% vegetative cover.

‡ Means within a column for inclusions followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($\alpha = 0.05$).

Recovery

Recovery ratings for May and June 2000, 2001, and 2002 following the wear imposed the previous fall, 1999, 2000, and 2001 for the main effects are shown (Table 2). The only significant inclusion by soil interaction occurred at the June 2001 rating (Fig. 3). There was no significant difference in recovery between the inclusion treatments in May and June of 2000 and 2002. Recovery in May 2001 for the control and Netlon treatments across both soils was significantly greater than the Sportgrass treatment. The reinforcement inclusion by soil interaction on June 2001 (Fig. 3), shows no difference in recovery among the inclusions on the silt loam. The recovery of turf on the Netlon and Turfgrid treatments, however, was significantly greater than the Sportgrass on the sand rootzone by the June ratings, although the recovery from these treatments was no better than the control. The turf growing in the silt loam soil showed significantly greater recovery than in the sand rootzone on two out of the six dates (Table 2). This is probably due to the natural fertility of the silt loam and its better moisture holding capacity compared with the sand rootzone.

Playing Quality Characteristics

The mean values for the main effects of the reinforcement inclusions and soils on surface hardness, traction, and ball roll are shown in Table 3. Because the trends for these three variables were similar for the three years, the data were combined and analyzed across years for the spring and fall periods. Ball rebound results are reported for the fall 1999 and 2000 and the spring and fall 2001 (Table 3).

Hardness

Sportgrass resulted in a significant increase in surface hardness relative to Netlon and the control in the spring, however, there was no difference between Turfgrids and Netlon or between Netlon and the control during the same period (Table 3). There was a significant inclusion by soil interaction for fall hardness that showed Sportgrass providing a significantly harder surface than the control in the silt loam and greater hardness than the control and Netlon in the sand rootzone (Fig. 4). Surface hardness in the Netlon, Turfgrids, and the control treatments did not differ in the silt loam, and Turfgrids had a significantly harder surface in the sand rootzone than either Netlon or the control. There was no difference in firmness between

Table 3. The means for surface hardness, traction and ball roll for reinforcement inclusions and soils across three years, and rebound resilience values for 1999, 2000, and 2001.

	Surface hardness		Traction		Ball roll		Rebound resilience			
	Spring	Fall	Spring	Fall	Spring	Fall	Fall 1999	Fall 2000	Spring 2001	Fall 2001
Inclusions	Gmax		N m		m		%			
Sportgrass	57.7a†	72.4a	50.9a	49.0a	5.4a	6.3a	37.6	35.5	33.9	36.4
Turfgrids	54.1ab	71.1a	48.7ab	44.8b	5.1ab	5.9b	36.5	35.3	33.6	36.7
Netlon	52.1bc	67.8b	48.1ab	44.5b	5.0b	5.8b	36.4	34.3	32.1	35.5
Control	48.9c	65.6b	46.7b	42.6b	4.9b	5.8b	35.8	36.0	32.9	36.6
Soils										
Sand rootzone	61.0	74.8	51.0	49.1	5.7	6.2	35.9	35.6	38.2	37.7
Silt loam	45.4	63.8	46.2	41.3	4.6	5.7	37.2	34.9	28.1	34.9
F test										
Inclusion (I)	**	**	**	**	**	**	NS	NS	NS	NS
Soils (S)	**	**	**	**	**	**	NS	NS	**	*
I x S	NS	*	NS	NS	NS	NS	**	*	NS	NS
CV%	5.4	3.0	3.8	5.2	5.2	2.0	5.6	6.3	4.5	6.4

*,**,NS Significant at $P < 0.05$, 0.01, and not significant ($P > 0.05$), respectively.

† Means within a column for inclusions followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test (alpha = 0.05).

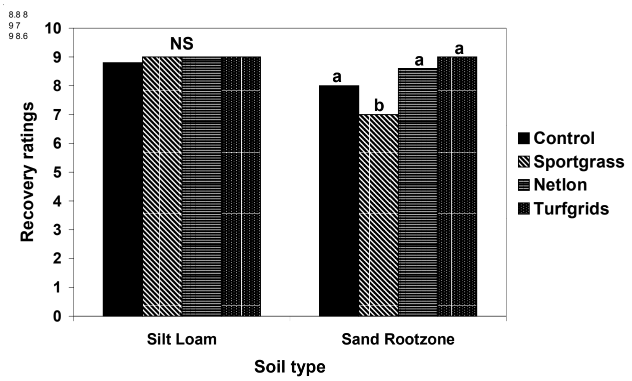

Figure 3. Effect of reinforcement inclusions x soil on turf recovery in June 2001. Recovery ratings 1 = 0–20% vegetative cover; 9 = 91–100% vegetative cover. Means for inclusions within a soil followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($\alpha = 0.05$).

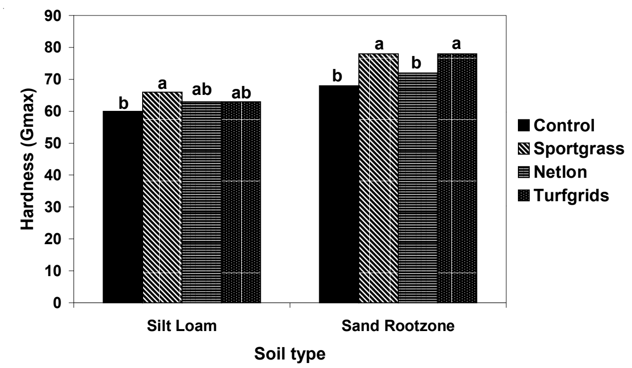

Figure 4. Effect of reinforcement inclusions x soil on surface hardness for fall ratings. Means for inclusions within a soil followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($\alpha = 0.05$).

the control and Netlon at any time. Richards (1994) reported that the difference between Netlon and control treatments for hardness were non-significant except for one out of four months in which the control registered a significantly firmer surface than Netlon. The study was carried out on a sand rootzone using a Clegg soil impact tester with a 0.5 kg missile. In our study, the missile weight of the Clegg meter was 2.25 kg. Surface hardness could not be compared to the standards for hardness suggested by Canaway *et al.* (1990) due to differences in the missile weight (0.5 kg) used by Canaway *et al.* and the missile weight of 2.25 kg used in our study.

The sand rootzone gave significantly greater hardness than the silt loam soil over all inclusion treatments in the spring and fall (Table 3). This is probably a result of the difference in soil moisture content between the two soils. Dest and Guillard (1999) reported a significant negative correlation ($r = -0.78$, $P < 0.01$) between soil moisture and hardness on soccer fields.

Traction

The mean traction values for inclusions across both soils for the spring and fall show significant differences (Table 3). Sportgrass gave significantly greater traction than the control in the spring although traction did not differ from the Netlon and Turfgrids treatments. However, in the fall season Sportgrass provided significantly greater traction than all the other three treatments, even though the Sportgrass had shown significantly more wear compared with the other treatments, particularly during the fall of 2000 and 2001. McNitt and Landschoot (2001) reported greater traction with Sportgrass compared with DuPont Shredded Carpet,

Table 4. Pearson correlation coefficients (r) relating bulk density, surface hardness, traction, and ball roll for spring and fall data, and air-filled porosity to infiltration and root weights.

	Spring		
	Hardness	Traction	Ball roll
Bulk density	0.85**	0.73**	0.82**
Hardness		0.91**	0.91**
Traction			0.81**
	Fall		
	Hardness	Traction	Ball roll
Bulk density	0.78**	0.77**	0.75**
Hardness		0.87**	0.85**
Traction			0.82**
	Infiltration	Root weights	
Air-filled porosity	0.75**	0.48**	

** Significant at P < 0.01.

Turfgrids, and a control over several dates, although the significance of the values varied between treatments based on the date traction was determined.

There was significantly greater traction in the spring and fall on the sand rootzone than the silt loam. However the traction values we found in the silt loam soil are well above the preferred minimum of 25 N m reported by Canaway *et al.* (1990), with mean values of 46.2 N m and 41.3 N m for spring and fall respectively. The inclusion by soil interaction was not significant in either spring or fall.

Ball Roll

Values for ball roll are shown in Table 3. Similar to what was found with the hardness and traction, ball roll significantly increased on Sportgrass relative to the control. In all instances, the distance rolled on Sportgrass was significantly greater than the other inclusions except for the spring values when there was no significant difference between Sportgrass and the Turfgrids treatments. The ball rolled a greater distance in the fall compared with the spring which may be accounted for by wear taking place at that period with its subsequent leaf damage and thinning the turf. A negative correlation was found between ground cover and rolling distance by Holmes and Bell (1986) and Dest and Guillard (1999).

The sand rootzone gave significantly greater rolling distance over all inclusions treatments than the silt loam in the spring and fall periods (Table 3). This may be a result of the sand providing a firmer surface. There was a highly significant correlation between hardness and rolling distance in the spring ($r = 0.91$) and fall ($r = 0.85$)

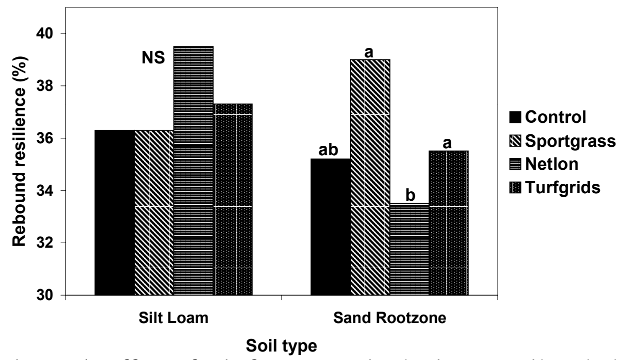

Figure 5. Effect of reinforcement inclusions x soil on ball rebound resilience for 1999. Means for inclusions within a soil followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($\alpha = 0.05$).

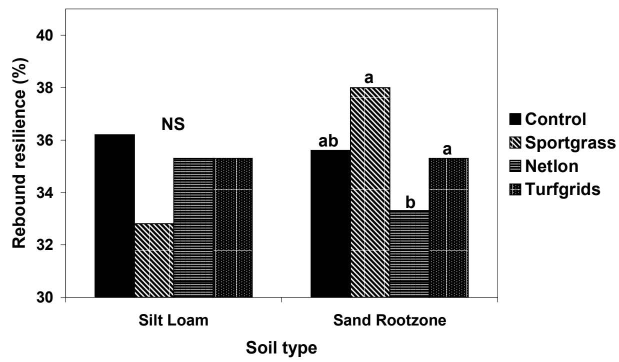

Figure 6. Effect of reinforcement inclusions x soil on ball bounce resilience for 2000. Means for inclusions within a soil followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($\alpha = 0.05$).

(Table 4). There was no inclusion by soil interaction for ball roll in either the spring or fall periods (Table 3).

Ball Rebound Resilience

There was an inclusion by soil interaction for ball rebound resilience in the spring 1999 and fall 2000 (Fig. 5 and 6). Ball rebound on the Sportgrass treatment was significantly higher than the Netlon on the sand rootzone in both years. Although rebound measurements determined on the silt loam showed a reverse effect between the Sportgrass and Netlon, the differences were not significant. The control and Turfgrids were not significantly different in rebound resilience to either Sportgrass or Netlon in both soils in 1999 and 2000.

There was a significant difference in ball rebound due to soil type over all inclusions in the spring and fall 2001 (Table 3). The sand rootzone resulted in a significantly greater resilient surface in both seasons than the silt loam. This may be due to the sand having a firmer surface and

Table 5. The mean infiltration rates, air-filled porosity values, total pore space, bulk density, and root weights for reinforcement inclusions and soils.

	Infiltration rate				Air-filled porosity	Total pore space	Bulk density	Root weights
	1999	2000	Spring 2001	Fall 2001				
	mm h^{-1}				%	%	g cm^{-3}	mg
Inclusions								
Sportgrass	323	292	330	310a†	16.8b	51.9ab	1.36a	112
Turfgrids	334	290	277	234b	22.4a	45.2c	1.25c	143
Netlon	254	282	323	241ab	20.1ab	50.3bc	1.32ab	162
Control	246	251	351	226b	19.4ab	52.4a	1.31b	180
Soils								
Sand rootzone	373	406	498	391	25.8	46.3	1.45	202
Silt loam	155	152	142	117	13.6	55.6	1.16	96
F test								
Inclusion (I)	NS	NS	NS	*	**	**	**	NS
Soils (S)	**	**	**	**	**	**	**	**
I x S	NS	NS	NS	NS	NS	NS	*	NS
CV%	24.4	23.5	27.6	20.1	13.2	2.2	2.2	35.8

*,**,NS Significant at $P < 0.05$, 0.01, and not significant ($P > 0.05$), respectively.

† Means within a column for inclusions followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($\alpha = 0.05$).

lower moisture content than the silt loam. Gibbs (2002) and Dest and Guillard (1999) reported a negative correlation between ball rebound resilience and soil moisture although only 15 to 20% of the change could be accounted for by soil moisture in both studies.

Soil Physical Properties

Infiltration Rate

The mean infiltration rates for inclusions and soils are shown in Table 5 for 1999, 2000, and 2001. There was no inclusion by soil interaction for infiltration. Differences among inclusions were observed only in the fall 2001, when Sportgrass had a significantly higher infiltration rate than the control and Turfgrids, while there was no significant difference between the control, Netlon and Turfgrids.

The sand rootzone conducted water two to three times the rate of the silt loam (Table 5). This is not unexpected given the difference in soil texture and air-filled porosity differences between the two soils (Table 5). Further, there was a significant correlation (r = 0 .75) between air-filled porosity and the infiltration rate measured in the fall 2001 (Table 4), which was at the same time that both infiltration was determined and undisturbed soil samples taken to determine air-filled porosity values. At least 55% of the infiltration variation between the two soils can be attributed to air-filled porosity values. However, given the difference in the magnitude of infiltration rates between the soils, the infiltration rate for the silt loam based on relative classes describing soil permeability (USDA Soil Survey, 1962) is moderately rapid to rapid (61 to 245 mm h^{-1}). The excellent flow in the silt loam was probably a function of tubular flow caused by earthworm activity. Earthworms are in abundance on the silt loam soil at the research center. Addition of earthworms has been shown to increase infiltration (Kladivko et al., 1986).

Air-Filled Porosity, Total Pore Space and Bulk Density

There was no inclusion by soil interaction for either air-filled porosity or total pore space. However, there was a significant difference in air-filled porosity and total pore space due to inclusions across soils and soil differences across all inclusions (Table 5). The mean air-filled porosity value for Sportgrass was significantly less than for Turfgrids. There was no difference in values between Turfgrids, Netlon, and the control, nor did air-filled porosity in the Netlon and control treatments differ significantly from the Sportgrass. This was also reflected in the total pore space values, except in reverse, where the total pore space in the Sportgrass treatment is significantly larger than the Turfgrids treatment. There was also a significant difference in means for total pore space between the control and Turfgrids.

The difference in air-filled porosity between the sand rootzone and silt loam was significant (Table 5). Air-filled porosity in the sand rootzone was 25.8% compared

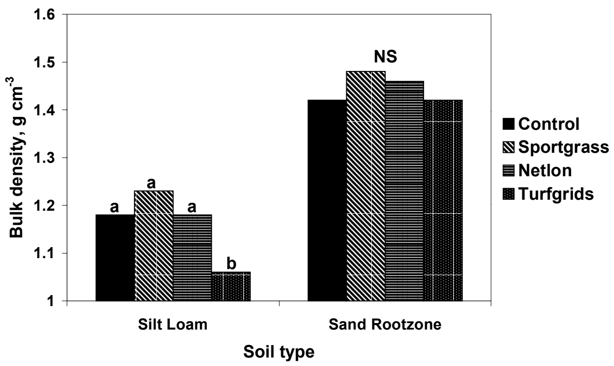

Figure 7. Effect of reinforcement inclusions x soil on bulk density. Means for inclusions within a soil followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($\alpha = 0.05$).

with 13.6% in the silt loam. However, given the mean air-filled porosity value of the silt loam, the value of 13.6% was still above the minimum value of 10%, a value below which aeration porosity can become deficient (Grable, 1971). The sand rootzone had a significantly lower total porosity than the silt loam (Table 5).

There was an inclusion by soil interaction for bulk density (Fig. 7). Turfgrids significantly lowered the bulk density in the silt loam compared with all other treatments. There was no effect on bulk density in the sand rootzone from inclusion treatments. The bulk density values found in our study do not indicate soil compaction occurred over the duration of the study. Bulk densities of the silt loam soils at the research center that we have measured range from 1.19 to 1.27 g cm^{-3}. The bulk density on the sand rootzones measure from 1.46 to 1.52 g cm^{-3}.

Root Weights

None of the reinforcement inclusion treatments had a significant effect on root growth compared with the control treatment (Table 5). There was no inclusion by soil interaction. The mean root weight in the sand rootzone was significantly greater than in the silt loam soil. This is partially a result of improved aeration porosity of the sand rootzone as shown by the relationship between air porosity values and root growth in which there was a highly significant positive correlation between the two (Table 4).

CONCLUSIONS

Although all the treatments showed increased damage from wear as the fall season progressed, none of the reinforcement inclusions improved wear tolerance relative to the control except on the silt loam in December 1999 when there was significantly less damage on the Sportgrass treatment compared with the control. However the difference in turfgrass wear between the two treatments did not affect the rate of recovery in the spring 2000.

There was significantly less damage from wear on the silt loam plots early in the fall than on the sand rootzone in the first two years of the study, likely a result of the natural fertility and better moisture holding capacity of the silt loam resulting in better growth after each wear treatment. However, this changed in 2001 with the sand rootzone providing significantly better turfgrass wear compared with the silt loam. This was a result of ingress of annual meadow-grass in the silt loam in which 42% of the turfgrass community comprised annual meadow-grass compared with 3% of the population in the sand rootzone suggesting an advantage of a sand rootzone in keeping annual meadow-grass populations low or the need to manage native soils to reduce the ingress of annual meadow-grass.

Sportgrass and Turfgrids significantly increased surface hardness relative to the control in the spring and fall while there was no difference in hardness between Netlon and the control in either the spring or fall season. There was also a significant difference in surface hardness in the fall between Turfgrids and Netlon on the sand rootzone, however there was no difference between the two treatments on the silt loam soil. This could be due to the higher soil moisture content of the silt loam exerting a greater influence over surface hardness than the two treatments.

The addition of Sportgrass significantly increased traction relative to the control in the spring and fall while no difference in traction occurred among the Turfgrids, Netlon and control over the same periods. Although there was no significant difference in traction among Sportgrass, Turfgrids and Netlon from the measurements made in the spring, Sportgrass significantly increased traction compared with these two treatments in the fall season. This may have resulted from the closer contact of the football studs with the polypropylene fibres as a result of decreasing turf density from wear.

The distance the ball rolled increased significantly on the Sportgrass compared with all other treatments in the spring and fall except for the spring when there was no significant difference between the Sportgrass and Turfgrids treatments. The greater rolling distance achieved with Sportgrass was due to the greater turfgrass damage from wear in the fall with loss of density and the slower rate or recovery in the spring 2000 and 2001 compared with the other treatments.

Surface hardness, traction and ball roll were significantly improved in the spring and fall on the sand rootzone compared with the silt loam. This is indicative of the firmer surface provided by the sand rootzone and shown by the positive correlation between bulk density and hardness, traction and ball roll.

Ball rebound resilience was less affected by treatments than the other playing quality characteristics except in the spring and fall 2001 when the sand rootzone provided a surface with significantly improved resilience compared with the silt loam. This was due to the sand rootzone's firmer surface and lower moisture content.

Although some of the reinforcement inclusions and the sand rootzone accounted for improved playing characteristics; traction, distance rolled and rebound resilience in the control and silt loam soil were within the proposed standards for Associated Football by Canaway *et al.* (1990).

Infiltration rates were not affected by the addition of reinforcement inclusions with the exception in the fall 2001 when the infiltration rate was significantly increased by Sportgrass relative to the Turfgrids and control treatments. Although not unexpected, the sand rootzone conducted water 2 to 3 times the rate of the silt loam. The greater amount of air-filled pores in the sand rootzone compared with the silt loam accounted for 55% of the increase in infiltration. However, given the difference in the infiltration rate between the sand rootzone and silt loam, the silt loam was still conducting water at a relatively rapid rate due to the abundant earthworm activity. Earthworm activity has been shown to benefit native soils by increasing infiltration and adding earthworms is recommended in some situations.

Based on our study, the use of reinforcement inclusions to provide better wear tolerance for athletic fields, whether a sand rootzone or native soil, is not warranted. Certain playing surface characteristics may be slightly improved with the use of reinforcement inclusions, but the greatest effect on playing quality characteristics and some of the physical properties of the soil important to a good playing surface were greatly improved by the use of sand construction methods. Therefore, sand construction methods or the use of sand topdressing on native soils to provide for a firmer surface and better playing quality characteristics should be encouraged.

ACKNOWLEDGMENTS

The authors thank Tom Griffen, Manager of the Joseph Troll Turf Research Center for his assistance in constructing the plots and for their subsequent maintenance over the life of the project and Lesley A. Spokas, Research Assistant, Department of Plant, Soil and Insect Science, University of Massachusetts for her assistance and use of the laboratory for determining pore space distribution.

REFERENCES

Adams, W.A., and R.J. Gibbs. 1989. The use of polypropylene fibres (VHAF) for the stabilization of natural turf on sports fields. p. 237-239. *In* H. Takatoh (ed.) Proc. of the Int. Turfgrass Res. Conf., 6th, Tokyo, Japan, 31 July – 5 August 1989. Int. Turfgrass Soc. and Japanese Soc. of Turfgrass Sci., Tokyo, Japan.

Adams, W.A., and R.J. Gibbs.1994. 'Natural Turf for Sports and Amenity: Science and Practice'. CAB International, Cambridge, 404 pp.

ASTM Standards F1815-97. 1999. Standard test method for saturated hydraulic conductivity, water retention, porosity, particle density and bulk density of putting green and sports turf root zones in Annual Book of ASTM Standard v. 15.07. American Society for Testing Materials, West Conshohocken, PA, pp. 1541-1546.

Baker, S.W., A.R. Cole, and S.L. Thornton. 1988. The effect of reinforcement materials on the performance of turf grown on soil and sand root zones under simulated football-type wear. J. Sports Turf Res. Inst. 64:107-119.

Baker, S.W., and R.J. Gibbs. 1989. Levels of use and the playing quality of winter game pitches of different construction types: case studies at Nottingham and Warrington. J. Sports Turf Res. Inst. 65:9-33.

Baker, S.W., and C.W. Richards. 1995. The effect of fibre-reinforcement on the quality of sand rootzones used for winter games pitches. J. Sports Turf Res. Inst. 71:107-117.

Beard, J.B. and S.I. Sifers.1990. Feasibility assessment of randomly oriented, interlocking mesh element matrices for turfed root zones. p. 154-165. *In* R.C. Schmidt et al. (ed.) Proc. of the Symp. on Characteristics and Safety of Playing Surfaces (Artificial and Natural) for Field Sports, Phoenix, AZ. 6 Dec. 1988. American Society for the Testing of Materials, West Cohonshocken, PA.

Bell, M.J., and G. Holmes. 1988. The playing quality of association football pitches. J. Sports Turf Res. Inst. 64:19-45.

Bertrand, A.E. 1965. Rate of water intake in the field. p. 202-207. *In* C.A. Black (ed.) Methods of Soil Analysis, Part 1. Agron. Monogr. 9. American Society of Agronomy, Madison, WI.

Blake, G.R. 1965. Bulk density. p. 375-377. *In* C.A. Black (ed.) Methods of Soil Analysis. Part 1. Agron. Monogr. No. 9. American Society of Agronomy, Madison, WI.

British Standards BS 7044: Section 2.1: 1989. Methods for determination of ball/surface interaction. British Standards Institute, London, UK.

Canaway, P.M. 1976. A differential slip wear machine (D.S.1.) for artificial simulation of turfgrass wear. J. Sports Turf Res. Inst. 52:92-99.

Canaway, P.M. 1994. A field trial on isotropic stabilisation of sand root zones for football using Netlon mesh elements. J. Sports Turf Res. Inst. 70:100-109.

Canaway, P.M. and M.J. Bell. 1986. Technical note: An apparatus for measuring traction and friction on natural and artificial playing surfaces. J. Sports Turf Res. Inst. 62:211-214.

Canaway, P.M., M.J. Bell, G. Holmes and S.W. Baker. 1990. Standards for the playing quality of natural turf for Association Football. *In* R.C. Schmidt et al. (ed.) Proc. of the Symp. on Characteristics and Safety of Playing Surfaces (Artificial and Natural) for Field Sports, Phoenix, AZ. 6 Dec. 1988. American Society for the Testing of Materials, West Cohonshocken, PA.

Clegg, B. 1976. An impact testing device for in situ base course evaluation. Australia Road Research Bureau Proc. 8:1-5.

Dest, W.M., and K. Guillard. 1999. Developing playing quality standards for natural turf athletic playing surfaces. p. 124. *In* 1999 Agron. Abst. American Society of Agronomy, Madison, WI.

Ferguson, M.H., L. Howard, and M.T. Bloodworth. 1960. Laboratory methods for evaluating putting green soil mixtures. USGA. J. of Turfgrass Management 13(5) 30-33.

Ferguson, M.H. 1965. After five years: The green section specifications for a putting green. USGA Green Section Record 3(4) 1-7.

Gibbs, R.J. 2002. Effect of Loksand fibre-reinforcement on a sand carpet rootzone under cool season and warm season turfgrass management. J. Sports Turf Res. Inst. 78:31-45.

Grable, A.R. 1971. Effects of compaction on content and transmission of air in soils. p. 154-164. *In* K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, G.E. VandenBerg (eds.) Compaction of Agricultural Soils. Am. Soc. Agric. Eng., St. Joseph, MI.

Holmes, G., and M.J. Bell. 1986. A pilot study of the playing quality of football pitches. J. Sports Turf Res. Inst. 62:74-91.

Kladivko, E.J., A.D. MacKay, and J.M. Bradford. 1986. Earthworms as a factor in the reduction of soil crusting. Soil Sci. Soc. Am. J. 50:191-196.

McNitt, A.S., and P.J. Landschoot. 2001. The effect of soil reinforcement inclusions in an athletic field rootzone. Int. Turfgrass Soc. Res. J. 9:565-572.

Richards, C.W. 1994. Effect of mesh element inclusion on soil physical properties of turfgrass root-zones. J. Sports Turf Res. Inst. 70:110-118.

SAS Institute. 1990. SAS/STAT User's Guide. Vol. 1 & 2. Version 6. 4th ed. Cary, NC.

USDA Soil Survey. 1962. Soil survey manual. USDA-SCS Agric. Handbook No. 18. U.S. Government Printing Office, Washington, D.C.

USGA Green Section Staff. 1993. USGA recommendations for putting green construction. USGA Green Section Record 31(2): 1-3.

Vomocil, J.A. 1965. Porosity. pp. 300-314. *In* C.A. Black (ed.) Methods of Soil Analysis, Part 1. Agron. Monogr. 9. American Society of Agronomy, Madison, WI.