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THE EFFECTS OF SOIL REINFORCING INCLUSIONS IN AN ATHLETIC FIELD ROOTZONE

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ABSTRACT

Reinforcing materials have been utilized in non-cohesive soil (sand) rootzones in attempts to increase the surface stability and improve the playability of athletic fields. Researchers in the civil engineering discipline have reported improved soil characteristics when reinforcing materials were amended into cohesive soils and exposed to heavy loads. The objective of this field study was to determine if the addition of DuPont Shredded Carpet, Sportgrass, and Turfgrids to a cohesive soil exposed to simulated foot traffic resulted in beneficial soil physical properties and playing surface quality.

The reinforcements studied in this experiment had limited and varying effects on turfgrass wear resistance, soil physical properties, and playing surface conditions. These effects were dependent on inclusion type and wear level. Individual inclusions tended to produce both limited benefits and detriments. The use of these inclusions in a cohesive-soil athletic field rootzone does not seem to be cost-effective.

Keywords

Sportgrass; Turfgrids; shredded carpet; traction; surface hardness; impact attenuation

INTRODUCTION

Various reinforcing materials have been mixed with athletic field rootzones in attempts to increase surface stability and minimize compaction. Baker [1997] reviewed much of the work that has been done on soil reinforcement for athletic fields. The majority of this work involved the effects of soil inclusions in non-cohesive soil (sand). Few researchers have evaluated the effects of fiber or fabric reinforcements on playing surface quality and soil physical properties of cohesive athletic field rootzones.

Researchers have found benefits to reinforcement of cohesive soil in civil engineering applications under heavy loads (confining stresses). Materials that have demonstrated reinforcement of cohesive soils include metallic and plastic grids [Jewell and Jones, 1981], spun nylon string, and polypropylene fibers [Freitag, 1987]. Benefits derived from these reinforcing materials include increased soil strength in wet conditions and reduced soil deformation under loads [Andersland and Khatak, 1979; Freitag, 1987]. Soil inclusions have proved beneficial in a variety of applications ranging from retaining structures and embankments to sub-grade stabilization beneath footings and pavements [Bassett and Last, 1978].

Synthetic materials mixed into soil for engineering applications are typically termed soil inclusions. Since the application of these synthetic materials to athletic field rootzones has been borrowed from the civil engineering discipline, these materials will be referred to as soil inclusions.

The majority of the athletic fields in the United States are constructed using cohesive soils. These fields, when subjected to heavy use, experience compaction, deformation, and reduced soil strength when soil moisture is high. The effects of soil inclusions on the playing surface quality of cohesive athletic field rootzones exposed to low confining stress is relatively untested. The objective of this research was to evaluate the benefits and detriments of three soil inclusion types on the soil physical properties and playing surface quality of a cohesive athletic field rootzone.

MATERIALS AND METHODS

Descriptions of the Inclusions

DuPont Shredded Carpet. DuPont Shredded Carpet was obtained from DuPont Nylon (Chestnut Run Plaza, Wilmington, DE) and is the shredded remains of carpet fragments that include both pile and backing. The shredded carpet is not commercially available, but is a component of a sand-based modular turfgrass system called GrassTiles™ (Hummer SportsTurf, Lancaster, PA). DuPont Shredded Carpet is approximately 70% nylon, 12.2% calcium carbonate, 10.7% latex, and 7.1% polypro-

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pylene on a weight basis [V.J. Kumar, personal communication, 1998]. Based on 100 randomly-selected carpet filaments, the average filament length was 135 mm, and the range was 20 to 610 mm. Fifteen carpet filaments were selected randomly and measured for width. The width of a carpet filament averaged 2.4 mm and ranged from 0.5 mm to 4 mm. When incorporated into soil, DuPont Shredded Carpet is randomly oriented.

Sportgrass™. Sportgrass is a commercially-available product manufactured by Sportgrass Inc. of McLean, VA. Sportgrass consists of a polypropylene woven backing with 24 yarn strand ends per 25.4 mm in the lineal direction and 11 yarn strand ends per 25.4 mm in width. Yarn strands are 1,100 denier (1.0 denier is equal to the fineness of a yarn weighing 1.0 g for each 9000 m). The woven backing is tufted with fibrillated polypropylene tufts. In the lineal direction there are 16 tufts per 102 mm. In width, the tufts are 9.5 mm apart. The pile height is 32 mm. The individual tufts form a net-like configuration when expanded. A fibrillated tuft is 6700 denier. [W. Cook, personal communication, 1998]. Sportgrass is an oriented fabric inclusion.

Turfgrids™. Turfgrids is a commercially available, polypropylene fiber inclusion manufactured by Synthetic Industries, Inc. (Chattanooga, TN). It is 99.4% polypropylene and individual fibers are 38 mm long and 5 mm wide. Each individual fiber is fibrillated to form a net-like structure of fine fibers or filaments (fibrils). When mixed with soil, each fiber expands and the net-like configuration of finer fibers is randomly oriented throughout the rootzone.

Plot Construction and Wear Treatments

In September 1995, a grid of 3.05 m by 3.05 m treatment plots was laid over level Hagerstown silt loam (fine, mixed Mesic Typic Hapludalf) topsoil. A 300 mm border composed of the Hagerstown soil surrounded each plot. The experimental design was a split block (blocks split by three levels of wear) with five treatments and three blocks. The five inclusion treatments for this experiment were DuPont Shredded Carpet 1% (0.01 kg kg^{-1} carpet and soil), DuPont Shredded Carpet 3% (0.03 kg kg^{-1} carpet and soil), Sportgrass, Turfgrids 1% (0.01 kg kg^{-1} carpet and soil), and a control with no soil inclusions. All of the treatments listed (with the exception of Sportgrass) were weighed and mixed with a screened (12.7 mm) Hagerstown silt loam topsoil using a front end loader on an asphalt mixing pad.

Wooden frames, 3.05 m by 3.05 m by 150 mm high, were installed on each of the plots and leveled using a transit. After filling the frames with the mixed rootzone treatments, the surface was leveled by raking and hand tamping. For the Sportgrass treatment, frames were installed and filled with the Hagerstown silt loam soil to within 25 mm of the top. The Sportgrass was then cut to fit the frames. Next, small amounts of a 90% sand:10% sphagnum peat (m^3 m^{-3}) topdressing meeting United States Golf Association specifications [Green Section Staff, 1993] was applied over the surface and worked into the pile using brooms. The plots were watered and allowed to dry, then more of the 90:10 mix was broomed into the pile. This process was repeated until approximately 3 mm of pile protruded above the settled mix. All frames were removed and the plots were seeded with 'SR 4200' perennial ryegrass (*Lolium perenne* L.) at a rate of 200 kg ha^{-1}. Phosphorus and potassium were applied at 49 and 98 kg ha^{-1} to the surface as per soil test recommendations. In the fall of 1995, nitrogen was applied at a rate of 75 kg ha^{-1}. During 1996 and 1997, nitrogen was applied in four applications of 49 kg ha^{-1} each. These applications occurred in early May and June, and late August and September of each year. The plot area was watered only to prevent wilting. The turf was cut with a reel mower twice per week at a height of 38 mm and the clippings were returned.

Wear level treatments were applied with a Brinkman Traffic Simulator [Cockerham and Brinkman, 1989]. The Brinkman Traffic Simulator weighed 410 kg and consisted of a frame housing two 1.2 m long rollers. Each roller had steel dowels or spriggs (12.7 mm diameter by 12.7 mm length) welded to the outside of the rollers, at an average of 150 dowels per m^2. These dowels were the approximate length and width of the cleats on the shoe of an American football lineman at the collegiate level. The Brinkman Traffic Simulator produced wear, compaction, and turf/soil lateral shear. The drive thrust yielding lateral shear was produced by different sprocket sizes turning the rollers at unequal speeds. The Brinkman Traffic Simulator was pulled with a model 420 tractor (Steiner Turf Equipment Inc., Dalton, OH) equipped with a dual turf tire package.

Blocks were split with three levels of wear. The wear levels were no-wear, medium-wear (three passes with the Brinkman Traffic Simulator three times per week), and high-wear (five passes three times per week). According to Cockerham and Brinkman [1989], two passes of the Brinkman Traffic Simulator is equivalent to turfgrass wear at the 40 yard line resulting from one National Football League game. Thus, 15 passes per week are equivalent to the wear sustained from 7.5 games per week.

In 1996, wear began on 19 July and ended on 18 Oct. In 1997, wear began on 2 June and ended 17 Oct. Typically, wear was applied regardless of weather conditions or soil water content. Numerous wear applications occurred when the soil water content was at or near saturation. Occasionally, due to heavy precipitation or schedule conflicts, wear was not applied on the scheduled day. In these cases, wear was applied on the following day.

Data Collection

The criteria for comparing treatments were turfgrass density, soil physical properties (bulk density, water content, and infiltration rate), and playing surface quality (hardness and traction).

Turfgrass density was rated visually and served as an estimate of both turfgrass cover and tillers per unit area. Density was rated using a scale of 0 to 5 with half units. A plot with no turfgrass present was rated as 0, and 5 indicated maximum cover and tiller density.

Soil bulk density data were derived from measurements of soil total density and volumetric water content taken with a Troxler 3400-B Series Surface Moisture-Density Gauge (Troxler Electronic Laboratories Inc., Research Triangle Park, NC). The Troxler Gauge uses neutron scattering simultaneously with gamma ray attenuation to measure the volumetric water content and bulk density of the soil [Gardner, 1986].

Because some inclusions could influence water content measurements, the Troxler Gauge was calibrated using a Tektronix™ 1502B time-domain reflectometry (TDR) unit (Tektronix Inc., Beaverton, OR). To calibrate the Troxler Gauge, water contents were determined from each treatment plot, using both the TDR and the Troxler Gauge, on six different occasions to provide a range of soil water contents. Linear relationships between the two methods for each inclusion treatment were evident, with regression coefficients greater than 0.90. Regression equations were calculated for each treatment. All water content values reported in this experiment were collected using the Troxler gauge and then adjusted using the appropriate regression equation. The values represent the water content in the surface 150 mm of rootzone mix.

Water infiltration rates were measured using double-ring infiltrometers [Bertrand, 1965]. Two concentrically-placed cylinders, 203 mm and 356 mm in diameter and 114 mm in height, were driven into the soil to a depth of approximately 25 mm. Three sets of cylinders were used to characterize each sub-plot. After an initial soaking period of 0.5 h, the cylinders were again filled with water and the rate of drop in the inner cylinder was measured. Because soil water infiltration rate data are not normally distributed, the statistical analysis of the data was performed after rates had been log transformed [Jury et al., 1991].

Surface hardness was measured using a Clegg Impact Tester (CIT) (Lafayette Instrument Company, Lafayette, IN) equipped with a 2.25 kg missile and a drop height of 450 mm [Rogers and Waddington, 1989]. Impact attenuation as measured by an accelerometer mounted on the missile was used to indicate surface hardness and is reported as Gmax, which is the ratio of maximum negative acceleration upon impact in units of gravities to the acceleration due to gravity. The average of six hardness measurements taken in different locations on each sub-plot was used to represent the hardness value of the sub-plot.

Linear traction measurements were taken with Pennfoot [McNitt et al., 1996, 1997] configured with a loading weight of 121.8 kg and a Nike™ high-top molded shoe. This shoe contained 18 triangular studs (12 mm long) around the perimeter of the sole and 35 smaller studs (9 mm long) in the center (Nike Inc., Beaverton, OR). The traction values reported are the average of traction measurements at three different locations on each sub-plot.

Rating Dates and Statistical Analysis

Turfgrass density, soil bulk density, soil water content, traction, and surface hardness data were collected on five dates. The dates were 27 Aug., and 19 Oct. 1996; and 18 June, 29 Aug., and 13 Oct. 1997. Water infiltration rates were measured from 4 Oct. to 7 Oct. 1996 and again from 6 Oct. to 10 Oct. 1997.

The turfgrass density rating and the means of the three soil bulk densities, three soil water contents, three traction values, six surface hardness measurements, and the log of the three water infiltration rates were analyzed as a split block design using analysis of variance and Fisher's Protected Least Significant Difference (LSD) test at the 0.05 level. A LSD was not calculated when the F ratio was not significant at the 0.05 level.

RESULTS AND DISCUSSION

Turfgrass Density

Mean turfgrass density ratings for wear levels across all inclusion treatments are shown in Table 1. On four of the five rating dates, each increase in wear intensity resulted in a significant decrease in turfgrass density. Recovery from wear was evident between the 19 Oct. 1996 and 18 June 1997 dates and between the August and October dates in 1997. Cool, moist conditions in combination with nitrogen applications may have contributed to the recovery of turfgrass density. There was no wear by inclusion treatment interaction on any date.

When averaged over all wear levels, turfgrass density differences due to inclusion treatments were small. Statistical differences were found on only two rating dates (Table 2). On the 19 Oct. 1996 rating date, the Sportgrass treatment had higher turfgrass density than all other treatments except the control and DuPont Shredded Carpet 1%. On the 29 Aug. 1997 rating date, Sportgrass had higher turfgrass density than all other treatments. Sportgrass may have measured higher in turfgrass density because the polypropylene backing and the 20 mm of sand topdressing worked into the Sportgrass pile may have prevented some surface compaction and crusting, thus allowing this treatment to withstand the effects of wear to a greater degree than the other treatments.

Table 1. Mean turfgrass density, soil bulk density, soil water content, surface hardness, and linear traction for wear level treatments averaged over soil inclusion treatments.

	1996		1997		
Wear Level	**27 Aug.**	**19 Oct.**	**18 June**	**29 Aug.**	**13 Oct.**
	Turfgrass Density				
	(0-5†)				
No wear	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**
Medium wear	**4.5**	**4.0**	**5.0**	**3.2**	**4.3**
High wear	**3.3**	**2.7**	**4.4**	**2.1**	**2.6**
LSD ‡ (0.05)	**0.2**	**0.1**	**0.2**	**0.2**	**0.4**
	Soil Bulk Density				
	(t m^{-3})				
No wear	**1.25**	**1.25**	**1.22**	**1.23**	**1.29**
Medium wear	**1.26**	**1.27**	**1.22**	**1.23**	**1.32**
High wear	**1.27**	**1.28**	**1.22**	**1.26**	**1.33**
LSD (0.05)	**NS**	**NS**	**NS**	**0.02**	**0.02**
	Soil Water Content				
	(m^3 m^{-3})				
No wear	**0.272**	**0.324**	**0.326**	**0.269**	**0.202**
Medium wear	**0.269**	**0.312**	**0.342**	**0.273**	**0.206**
High wear	**0.266**	**0.301**	**0.340**	**0.249**	**0.191**
LSD (0.05)	**NS**	**0.011**	**NS**	**NS**	**NS**
	Surface Hardness				
	(Gmax)				
No wear	**59**	**50**	**52**	**69**	**95**
Medium wear	**71**	**65**	**58**	**91**	**125**
High wear	**79**	**74**	**64**	**105**	**137**
LSD (0.05)	**6**	**6**	**4**	**5**	**5**
	Linear Traction				
	(Newtons)				
No wear	**1238**	**1347**	**1188**	**1175**	**1382**
Medium wear	**1302**	**1425**	**1321**	**1231**	**1400**
High wear	**1285**	**1379**	**1194**	**1190**	**1409**
LSD (0.05)	**NS**	**NS**	**43**	**38**	**NS**

† Visual estimate turf cover and tillers per unit area, 0 represents no turfgrass present and 5 represents maximum turfgrass cover and density.

‡ Fisher's protected least significant difference test.

In this study, all inclusion treatments, other than Sportgrass, measured lower in turfgrass density than the control on the 29 Aug. 1997 rating date but did not differ from the control on the other four rating dates.

Soil Bulk Density

Mean soil bulk density values for wear levels across all inclusion treatments are shown in Table 1. In 1996, there were no differences among wear levels, whereas in 1997, soil bulk density differences due to wear were found on the 29 Aug. and 13 Oct. 1997 rating dates. The high-wear level had a higher soil bulk density than the no-wear level on the 29 Aug. and 13 Oct. 1997 rating dates. The medium-wear level was significantly higher in bulk density than the no-wear level on the 13 Oct. 1997 rating date. There was no wear by inclusion treatment interaction on any date.

Soil bulk density values due to inclusion treatments across all wear levels are shown in Table 2. Few differences were found among treatments other than Sportgrass. On the three rating dates where differences were detected, Sportgrass had soil bulk density values higher than most treatments. The Sportgrass may have had a higher soil bulk density than other treatments because of the 20 mm of sand topdressing placed on the surface. Sand typically has a higher soil bulk density than silt loam soil and the Troxler gauge measures bulk density over the distance between the photon source and the receiver, in this case 150 mm.

Soil Water Content

Overall, few soil water content differences were measured among wear levels when averaged over all inclusion treatments (Table 1). On the 19 Oct. 1996 rating date, the no-wear level had the highest soil water content and the high-wear level had the lowest soil water content. This may be due to the medium- and high-wear plots having less turfgrass cover than the no-wear plots. Less turfgrass cover has been shown to cause an increase in soil temperatures [Agnew, 1984] which may result in a decrease in soil water content. There was no wear by inclusion treatment interaction on any date.

Soil water content values due to inclusion treatments are shown in Table 2. In most cases, the addition of any of the soil inclusions to this silt loam soil reduced soil water content. The addition of 3% DuPont Shredded Carpet reduced soil water content more than the addition of Sportgrass or the DuPont Shredded Carpet 1% treatments. McNitt [2000] reported that Sportgrass consistently reduced soil water content in a sand soil. In the current experiment, Sportgrass reduced soil water content less than the other inclusions and on one rating date, Sportgrass had a soil water content higher than all other treatments. The highest soil water contents usually occurred with Sportgrass and the control.

Infiltration Rate

Significant water infiltration rate differences due to wear levels and inclusion treatments are shown in Tables 3 and 4, respectively. A significant wear level by inclusion treatment interaction occurred in 1996 (Table 5).

The wear level by inclusion treatment interaction data in Table 5 indicates that under the no-wear level all inclusion treatments maintained an infiltration rate above 120 mm h^{-1}. Compared to the no-wear level, all inclusion treatments showed a decrease in infiltration rate under medium- and high-wear; however, the decrease was most pronounced for the control treatment which decreased from 126 to 19 mm h^{-1}. Compared to the control (19 mm h^{-1}), all inclusion treatments gave a higher infiltration rate ($\geq$58 mm h^{-1}) under the medium-wear level with Sportgrass having an infiltration rate

Table 2. Mean turfgrass density, soil bulk density, soil water content, surface hardness, and linear traction for soil inclusion treatments averaged over wear levels.

	1996		1997		
Treatment	27 Aug.	19 Oct.	18 June	29 Aug.	13 Oct.
	Turfgrass Density				
	(0-5 †)				
Control	4.4	3.9	4.8	3.5	4.1
DuPont Shredded Carpet 1%	4.2	3.9	4.8	3.3	3.9
DuPont Shredded Carpet 3%	4.2	3.8	4.8	3.3	4.0
Sportgrass	4.4	4.1	4.9	3.8	4.0
Turfgrids 1%	4.2	3.8	4.7	3.3	3.8
LSD ‡ (0.05)	NS	0.2	NS	0.2	NS
	Soil Bulk Density				
	($t\ m^{-3}$)				
Control	1.26	1.26	1.19	1.23	1.31
DuPont Shredded Carpet 1%	1.23	1.23	1.23	1.23	1.32
DuPont Shredded Carpet 3%	1.26	1.28	1.21	1.23	1.30
Sportgrass	1.28	1.30	1.25	1.27	1.31
Turfgrids 1%	1.24	1.26	1.21	1.24	1.33
LSD (0.05)	NS	0.04	0.02	0.03	NS
	Soil Water Content				
	($m^3\ m^{-3}$)				
Control	0.281	0.344	0.375	0.286	0.210
DuPont Shredded Carpet 1%	0.268	0.307	0.324	0.266	0.194
DuPont Shredded Carpet 3%	0.240	0.276	0.297	0.234	0.172
Sportgrass	0.284	0.324	0.341	0.274	0.244
Turfgrids 1%	0.272	0.311	0.343	0.259	0.179
LSD (0.05)	0.016	0.014	0.013	0.017	0.012
	Surface Hardness				
	(Gmax)				
Control	71	64	54	86	114
DuPont Shredded Carpet 1%	67	61	56	88	117
DuPont Shredded Carpet 3%	66	58	52	87	117
Sportgrass	73	71	68	89	112
Turfgrids 1%	72	63	59	93	135
LSD (0.05)	NS	8	4	NS	6
	Linear Traction				
	(Newtons)				
Control	1245	1384	1231	1207	1351
DuPont Shredded Carpet 1%	1245	1390	1251	1211	1423
DuPont Shredded Carpet 3%	1207	1377	1270	1202	1403
Sportgrass	1424	1426	1203	1185	1449
Turfgrids 1%	1255	1338	1216	1188	1359
LSD (0.05)	89	54	NS	NS	50

† Visual estimate turf cover and tillers per unit area, 0 represents no turfgrass present and 5 represents maximum turfgrass cover and density.

‡ Fisher's protected least significant difference test.

higher than all other treatments (183 mm h^{-1}).

Under the high-wear level all inclusion treatments resulted in decreased infiltration rates compared to the medium-wear level, except Sportgrass which was unchanged (Table 5). The polypropylene backing plus the sand topdressing in the Sportgrass may have protected the underlying silt loam soil from crusting and/or compacting, thus maintaining a relatively high infiltration rate under high-wear levels.

All inclusion treatment infiltration rates increased slightly from 1996 to 1997. Similar trends in infiltration rates due to inclusion treatments were evident in the 1997 data although no statistical infiltration rate differences were found in 1997 (Table 4).

Surface Hardness

Mean surface hardness values for wear levels across inclusion treatments are shown in Table 1. A trend is evident, with the high-wear level plots measuring highest in surface hardness, the no-wear plots measuring lowest in surface hardness, and the medium-wear plots being intermediate.

The surface hardness values for the inclusion treatment by wear level interaction were significant only on the 13 Oct. 1997 rating date (Table 6). All inclusion treatments increased in surface hardness as the wear level increased. Under no-wear, the control had a surface hardness value lower than all other treatments. Under medium- and high-wear, all treatments had similar surface hardness values except the Turfgrids 1% treatment, which had a surface hardness value higher than all other treatments. On this rating date, under somewhat dry soil conditions, the surface hardness values of all the medium- and high-wear level plots were high compared to values for heavily used fields (60-98 Gmax) reported by Rogers et al. [1988].

Surface hardness values due to inclusion treatments are shown in Table 2. The addition of Sportgrass and Turfgrids 1% to this silt loam soil increased surface hardness, relative to the control on some rating dates under some wear levels. The addition of DuPont Shredded Carpet 1% and 3% produced no measurable change in surface hardness compared to the control. In a sand rootzone, McNitt (2000) found a significant and consistent increase in surface hardness due to the Sportgrass and Turfgrids inclusion treatments and a dramatic decrease in surface hardness with increasing rates of DuPont Shredded Carpet. Results from the present silt loam soil study show a muted response, with inconsistent increases in surface hardness due to the addition of Sportgrass and Turfgrids, and no change with the addition of DuPont Shredded Carpet.

The data in Tables 2 and 6 indicate that there was a larger range of hardness values from one date to another compared to the range among inclusion treatments on a single rating date. A close examination of the data in Table 2 shows that soil water content is likely a major contributing factor to the wide range in surface hardness among dates. Over the five sampling dates, average soil water content ranged from 0.20 to 0.34 $m^3\ m^{-3}$. This increase corresponded with a decrease in average surface hardness values from 119 to 58 Gmax. While wear levels and inclusion treatments affected surface

Table 3. Mean water infiltration rates and log transformed values for wear levels when averaged over soil inclusion treatments.

	Infiltration rate			
Wear Level	Oct. 1996		Oct. 1997	
	(mm h^{-1})	(log mm h^{-1})	(mm h^{-1})	(log mm h^{-1})
No wear	176	11	202	12
Medium wear	79	6	150	8
High wear	52	2	47	4
LSD ‡ (0.05)		2		2

‡ Fisher's protected least significant difference test.

Table 4. Mean water infiltration rates and log transformed values for soil inclusion treatments averaged over wear levels.

Treatment	Infiltration rate Oct. 1996 (mm h^{-1})	 (log mm h^{-1})	Oct. 1997 (mm h^{-1})	 (log mm h^{-1})
Control	52	3	76	9
DuPont Shredded Carpet 1%	100	7	121	12
DuPont Shredded Carpet 3%	80	5	123	12
Sportgrass	212	13	259	14
Turfgrids 1%	69	4	84	9
LSD ‡ (0.05)		3		NS

‡ Fisher's protected least significant difference test.

hardness, soil water content seems to have had a greater effect on surface hardness. The correlation coefficient for soil water and surface hardness (-0.77**) was significant (Table 7). This relationship is consistent with the findings of other researchers [Baker and Bell, 1986; Rogers et al., 1988; Rogers and Waddington, 1990]. Surface hardness was also correlated with soil bulk density (0.60**), and turfgrass density (-0.41**) (Table 7).

Linear Traction

Mean linear traction values for wear levels across all inclusion treatments are shown in Table 1. Traction differences occurred on only two rating dates, with the medium-wear level plots measuring highest in traction. There were no traction differences between the no-wear and high-wear level plots. These results are consistent with those reported by McNitt [2000] where similar wear levels, on a sand rootzone, resulted in the medium-wear plots measuring highest in traction. While these differences are small, the data indicate that as wear levels increase, traction increases (perhaps due to compaction and surface firming) until the wear causes a decrease in turfgrass density at which time traction decreases. The relationship between traction and turfgrass density in this study was of minor practical importance as indicated by a correlation coefficient of -0.14 (Table 7). This result is in contrast to the findings of McNitt et al. [1997] where turfgrass density had a significant effect on traction. McNitt et al. [1997] conducted their study on silt loam soil that contained no inclusions and density differences were created by varying mowing height. No simulated traffic was applied. There was no wear level by inclusion treatment interaction for traction values on any rating date.

Mean traction differences due to treatments are listed in Table 2. While the traction values for treatments varied, Sportgrass had the highest traction on three of the five rating dates. On the 27 Aug. 1996 rating date, the Sportgrass treatment measured significantly higher in traction than all other treatments. On the 19 Oct. 1996 rating date, the Sportgrass treatment measured significantly higher in traction than the Turfgrids 1% treatment and on the 13 Oct. 1997 rating date, the Sportgrass treatment measured significantly higher in traction than the Turfgrids 1% and the control. The magnitude of the traction differences measured on 19 Oct. 1996 and 13 Oct. 1997 was small in comparison to those measured on 27 Aug. 1996.

SUMMARY AND CONCLUSIONS

The soil inclusions studied in this experiment had limited and varying effects on turfgrass density, soil physical properties, and playing surface conditions. These effects were dependent on inclusion type and wear level. Individual inclusions tended to produce both limited benefits (e.g. increased turfgrass density) and detriments (e.g. increased surface hardness).

Turfgrass density differences due to inclusion treatments were minor. The Sportgrass treatment resulted in turfgrass densities that were higher than all other treatments on two of five rating dates. The Sportgrass backing, pile, and sand topdressing may have

Table 5. Mean water infiltration rates and log transformed values for the treatment by wear interaction in 1996.

Treatment	Infiltration Rate no wear (mm h^{-1})	 (log mm h^{-1})	medium wear (mm h^{-1})	 (log mm h^{-1})	high wear (mm h^{-1})	 (log mm h^{-1})
Control	126	9	19	-1	12	-1
DuPont Shredded Carpet 1%	207	12	68	6	24	3
DuPont Shredded Carpet 3%	145	11	68	4	28	-1
Sportgrass	269	14	183	12	184	13
Turfgrids 1%	134	10	58	7	13	-44
LSD ‡ (0.05)	-	5	-	5	-	5

‡ Fisher's protected least significant difference test.

Table 6. Mean surface hardness values for the treatment by wear level interaction on Oct. 13 1997 rating date.

Treatment	Surface Hardness		
	Wear Level		
	none	medium	high
	(Gmax)		
Control	87	123	134
Dupont Shredded Carpet 1%	98	122	132
Dupont Shredded Carpet 3%	97	125	129
Sportgrass	90	120	126
Turfgrids 1%	105	136	163
LSD ‡ (0.05)	11	11	11

‡ Fisher's protected least significant difference test.

protected the silt loam soil surface.

The higher turfgrass density measured in the Sportgrass treatment is in contrast to results obtained by McNitt [2000] using Sportgrass on a sand rootzone. In the sand rootzone, McNitt [2000] found consistently lower turfgrass density for Sportgrass compared to sand alone, indicating that the pile and backing reduced turfgrass wear resistance. In the present silt loam soil study, Sportgrass topdressed with sand supported turf that was less susceptible to wear than turf on the silt loam soil. Future research involving Sportgrass should include a control with sand topdressing over a cohesive soil in an attempt to distinguish between the effects of the pile, backing, and sand topdressing.

Soil bulk density was unaffected by the treatments with one exception. Sportgrass had a higher soil bulk density than all other treatments on three rating dates. Again, this may be due to the sand topdressing causing a higher average soil bulk density.

The soil inclusion treatments generally reduced soil water content compared to the control. The addition of 3% DuPont Shredded Carpet resulted in a soil water content lower than all other treatments on four of the five rating dates. The control measured higher in soil water than all inclusion treatments on two rating dates. The reason the soil inclusions reduced soil water content is not immediately apparent.

The addition of inclusions increased water infiltration rates over the control during 1996. The water infiltration rates for inclusion treatments in 1997 indicated the same trend but differences between treatments and the control were not significant. The long-term effect of soil inclusions on infiltration rates of cohesive soils is impossible to predict from these data.

Table 7. Correlation coefficients (n=75) between measured plot characteristics.

	Surface Hardness	Soil Water	Soil Bulk Density	Turfgrass Density
Traction	0.26 **	-0.19 **	0.52 **	-0.14 *
Surface Hardness	-	-0.77 **	0.60 **	-0.41 **
Soil Water		-	-0.58 **	0.22 **
Soil Bulk Density			-	-0.27 **

* = significant at 0.05 level, ** = significant at 0.01 level.

The addition of Sportgrass and Turfgrids 1% to this silt loam soil increased surface hardness, relative to the control, on some rating dates under some wear levels. The addition of DuPont Shredded Carpet 1% and 3% produced no measurable change in surface hardness compared to the control. The results indicate that surface hardness was influenced to a greater degree by soil water than by inclusion treatments.

Overall, few traction differences were measured, but the medium-wear level tended to have higher traction values than the high- or no-wear levels. This could be due to some firming of the surface with only minimal loss of turfgrass density.

Under high confining stress (heavy loads), certain inclusion types have improved soil physical characteristics for engineering applications. The basis for conducting this study was to determine if any benefits or detriments would occur if soil inclusions were used in a cohesive athletic field rootzone under low confining stress. Because the inclusions in this study were associated with little change, the use of these materials on cohesive-soil athletic fields does not seem to be cost effective. However, we do not rule out the possibility that these inclusions could provide benefits in other non-athletic field turfgrass uses. Areas that may benefit would include turfgrass parking lots, turfgrass fire lanes and emergency access areas where a cohesive soil must support the weight of large vehicles which produce a higher confining stress than experienced on athletic fields. A study on such areas should measure soil strength, compression, rutting, and vehicular traction under varying weather, soil, and turfgrass conditions.

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REFERENCES

Agnew, M. L. 1984. Canopy/soil temperatures and acclimation responses of Kentucky bluegrass to soil compaction and moisture stress. Ph.D. Diss. Kansas State Univ., Manhattan (Diss. Abstr. 84-28123).

Andersland, O.B., and A.S. Khatak, 1979. Shear strength of kaolinite/fiber soil mixtures. Proc. Int. Conf. on Soil Reinforcement 1:11-16.

Baker, S. W. 1997. The reinforcement of turfgrass areas using plastic and other synthetic materials: a review.

Int. Turfgrass Soc. Res. J. 8:3-13.

Baker, S. W., and M. J. Bell. 1986. The playing characteristics of natural turf and synthetic turf surfaces for association football. J. Sports Turf Res. Inst. 62:9-35.

Bassett, R. H., and C. N. Last. 1978. Reinforcing earth below footings and embankments. American Society of Civil Engineers Symposium on Earth Reinforcement, pp. 222-231. Pittsburgh, PA.

Bertrand, A. E. 1965. Rates of water intake in the field. pp. 202-204. *In* C. A. Black (ed.) Methods of Soil Analysis. Part 1-Physical and Mineralogical Methods-Agronomy Monograph #9 (1st Edition). American Society of Agronomy, Madison. WI.

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

Cockerham, S.T., and D.J. Brinkman. 1989. A simulator for cleated-shoe sports traffic on turfgrass research plots. California Turfgrass Culture 39:9-10.

Freitag, D.R. 1987. Soil randomly reinforced with fibers. J. Geotech. Eng. 112:823-826.

Gardner, W. H. 1986. Water content. pp. 493-544. *In* A. Klute (ed.) Methods of Soil Analysis. Part 1-Physical and Mineralogical Methods-Agronomy Monograph #9 (2nd Edition). American Society of Agronomy, Madison, WI.

Green Section Staff. 1993. USGA recommendations for a method of putting green construction. United States Golf Association Green Section Record 31(2):1-3.

Jewell, R.A., and C.J.F.P. Jones. 1981. Reinforcement of clay soils and waste materials using grids. Proc. 10th Int. Conf. of Soil Mechanic and Foundations Engineering 3:701-706.

Jury, W.A., W.R. Gardner, and W.H. Gardner. 1991. Soil Physics. 5th ed. John Wiley and Sons, Inc. New York, NY.

McNitt, A. S. 2000. The effects of soil inclusions on soil physical properties and athletic field playing surface quality. Ph.D. Diss. Pennsylvania State University, University Park, PA.

McNitt, A. S., D. V. Waddington, and R. O. Middour. 1996. Traction measurement on natural turf. pp. 145-155. *In* Earl F. Hoerner (ed.) Safety in American Football. Standard Technical Publication 1305. American Society for Testing Materials. West Conshohocken, PA.

McNitt, A. S., R. O. Middour, and D. V. Waddington. 1997. Development and evaluation of a method to measure traction on turfgrass surfaces. J. Testing and Evaluation 25(1):99-107.

Rogers III, J.N., and D.V. Waddington. 1989. The effect of cutting height and verdure on impact absorption and traction characteristics in tall fescue turf. J. Sports Turf Res. Inst. 65:80-90.

Rogers III, J.N., and D.V. Waddington. 1990. Effects of management practices on impact absorption and shear resistance in natural turf. pp. 136-146. *In* R.C. Schmidt et al. (eds.) Natural and artificial playing fields: characteristics and safety features. Standard Technical Publication 1073. American Society for Testing Materials. Philadelphia, PA.

Rogers III, J.N., D.V. Waddington, and J.C. Harper. 1988. Relationships between athletic field hardness and traction, vegetation, soil properties, and maintenance practices. Progress Report 393. The Pennsylvania State University, College of Agriculture Experiment Station. University Park, PA. 15 pp.