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Management of SportGrass for athletic fields

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Management of SportGrass for athletic fields

by

Jay Scott Hudson

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Horticulture

Major Professor: David D. Minner

Iowa State University
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Iowa State University

This is to certify that the Master's thesis of

Jay Scott Hudson

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
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CHAPTER 1. GENERAL INTRODUCTION

Historically, athletic fields were little more than grass grown on native soil. These fields, however, were plagued by poor drainage and often became damaged during wet or muddy conditions, thus creating maintenance problems (Pahulla et al., 1999). During the 1960's, several circumstances led to the development of a more uniform, synthetic surface. The first circumstance was the necessity to find a safe playing surface for city children to use. The Ford Foundation found a refuge in the carpet industry, which they installed in school gymnasiums (Morehouse, 1992). Another factor in the development of synthetic turf was the completion of the Houston Astrodome, the first indoor playing facility (Morehouse, 1992). Transparent panels were installed in the roof of the doom to promote the growth of natural grass, but the players were unable to see fly balls due to the glare of sunlight through these panels. The panels were then painted. Under artificial lighting and heavy use, however, the grass was unable to survive and within one year of its opening, the Astrodome was equipped with a synthetic turf called Astroturf (Morehouse, 1992).

Artificial turf was easy to maintain and could withstand heavy use without losing its playing characteristics. As the popularity of synthetic turf increased through the 1970’s and 1980’s, however, questions arose over player safety. Synthetic surfaces were hard and resulted in high incidence of injuries, particularly knees and ankles (Powell and Schootman, 1992; 1993). More recently, the trend in the turf grass industry has been for newly constructed and renovated athletic fields to be converted back to natural grass with the utilization of a sand-based root zone. With modifications in the 1990's to the United States Golf Associations specifications for sand-based root zones (USGA, 1993), these rapid
draining systems have become the most widely used method for the construction of golf course greens and athletic fields (Minner, 2000).

A drawback to sand-based systems, however, is that it can result in an unstable playing surface, especially when the grass has worn away. In the past several years, many reinforcement materials have been developed (e.g., Enkamat, Turfgrids, Netlon) to stabilize the playing surface of sand-based systems and improve general playing conditions. SportGrass is the first product that combines the playability of natural grass with some of the durable characteristics of synthetic turf.

The SportGrass system consists of a natural grass playing surface that is grown into a synthetic matrix and installed on a sand-based root zone (SportGrass Athletic Surfacing, 2000). The synthetic matrix of the SportGrass system used in this study was comprised of fibrillated fibers (polypropylene grass blades) tufted into a woven backing. The backing material was made from polypropylene strands woven together at a rate of 12 pique. The green fibrillated fibers, 8000 denier polypropylene, were needle-punched into the woven backing at a stitch rate of 11 stitches per 7.5 cm. Stitch rows were produced from needles placed on 1.0-cm centers. The needle-punched fibrillated fibers were trimmed to produce polypropylene grass blades with a length of 3.2 cm (SportGrass Inc., McLean, VA). The manufacturers of SportGrass claim that when properly maintained, their product: 1) provides protection of the crown and root system of the plant because roots grow down through the synthetic matrix; 2) retains a stable playing surface during times when the natural grass has temporarily worn away; 3) eliminates divots, ruts, and bare spots that result from heavy traffic, thereby reducing the need for renovation and frequent repairs; 4) lasts longer than synthetic turf playing surfaces.
Since SportGrass is a relatively new innovation in turf management, there is little quantitative evidence lending support to its proposed benefits as a reinforcement material. Compared to a nonreinforced control, SportGrass reduced divot length and soil water content while increasing surface hardness (McNitt, 2000). The objectives of this study were to evaluate the playing qualities of SportGrass when subjected to various turfgrass management practices and to determine the effects of traffic on the bulk density, saturated hydraulic conductivity, and dry root mass.

**Thesis Organization**

This thesis consists of one manuscript intended for publication in Crop Science. Various conventional turfgrass management practices were tested on the SportGrass system and then compared to nonreinforced natural grass. A general introduction and literature review precedes the manuscript. A general conclusion succeeds the manuscript. An additional reference section, with literature citations from the general introduction, literature review, and general conclusion follows at the end of the thesis. Jay Scott Hudson conducted the research and is the primary author of the manuscript. Dr. David D. Minner designed and established the study area, and was instrumental in the completion of this study through advising, obtaining funding, and editing this thesis.
CHAPTER 2. LITERATURE REVIEW: AN EVALUATION OF REINFORCEMENT MATERIALS FOR ATHLETIC FIELDS

Introduction

While it may be argued that playing quality is just an abstract concept based on our own perceptions of how a given surface plays, there nevertheless exists some objective measurements that can be made which correlate with these perceptions (Canaway and Baker, 1993). These include ball rebound, ball roll, traction, and hardness. Similarly, wear (or traffic) affects ground cover, and this in turn can affect the above measurements. In fact, Canaway and Baker (1993) state that playing quality is determined by the nature of the main components of turf (plant and soil) and the way that these interact with wear.

Throughout its history, several innovations have changed the face of turfgrass management. Originally, fields were little more than natural grass mowed and painted before competition. Then came the use of a more durable playing surface, synthetic turf. Today, as athletic fields are shifting back to natural grass, the addition of reinforcement materials is growing in popularity. The aim of this paper is to discuss how the use of reinforcement materials promote or compromise the performance of athletic fields.

Improvement of Playing Quality with Reinforcement Materials

Playing quality of athletic fields can be identified by two different but related interactions between the surface and the player, and between the surface and the ball (Bell et al., 1985; and Canaway, 1985). Interactions between the surface and the player include surface hardness and traction. Surface hardness, which Bell et al. (1985) defined as the effect
the surface has on absorbing impact energy created by a player. Hard surfaces can be
dangerous to players in terms of injuries, such as concussions or neck injuries, whereas soft,
spongy fields can create early fatigue in the leg muscles of players. The second effect on a
player is traction, which Bell et al. (1985) defined as the type of footing a playing surface
provides. A wet field with little ground cover offers little traction and may cause players to
slip and fall. The other interaction involved in playing quality is the effect a field has on the
ball. A bumpy, sparsely covered field, for example, can cause the ball bounce and/or roll to
be unpredictable, as well as adversely affect a player's footing, risking ankle or knee injury.
In sand-based systems, player safety and performance is most jeopardized during high wear
when the grass has worn away exposing the surface and reducing stability (Holmes and Bell,
1986).

The use of reinforcement materials began with applications from civil engineering
aimed at stabilizing and improving the performance of soils (Ingold and Miller, 1988).
Types of materials used include woven fabrics, non-woven fabrics, knitted fabrics, meshes,
and grids (Ingold and Miller, 1988). More recently, interest in stabilizing turfgrass has
focused on the reinforcement of root zones. During intense traffic, turfgrass wears away and
the ability of its roots to stabilize the playing surface becomes diminished (Adams et al.,
1985 and Gibbs et al., 1989). This, in turn, can adversely affect player performance and
safety. Reinforcement materials add the stability to the playing surface that the roots are no
longer able to offer (Baker, 1997).

Reinforcement material improves the wear tolerance and quality of turf through
several mechanisms (Baker, 1988b). First, reinforcement material helps spread the force
created during contact with the ground (load spreading) thus, reducing the rate of soil
compaction. Second, reinforcement material reduces the effects of shearing forces (tearing), helping to preserve the continuity of large pores at the soil surface. Third, reinforcement material offers the crown tissue of grass plants protection from heavy wear and damage. Finally, the interaction between the fibers in the reinforcement material and the studs on the player's footwear increases traction.

Reinforcement materials can be classified into two broad categories. Firstly, those that form a horizontal layer at or near the turf surface and, secondly, those that are mixed or punched directly into the root zone (Baker, 1997). The different types of reinforcement materials that have been produced are described in Table 1.

### Influence of Reinforcement Materials

#### Ground Cover

Ground cover is the measure of green vegetation in a given area, typically a percentage, and is usually considered an indicator of the amount of wear that has occurred. Several studies have examined the effects of reinforcement materials on ground cover when subjected to football-type wear on both sandy loam topsoil and sand root zones. The use of Enkamat as a reinforcement material did not increase ground cover compared to nonreinforced controls and did not show any advantages during high wear (Schmidt, 1982a,b). Ground cover of perennial ryegrass was reduced more rapidly during wear on the soil area than the sand root zone for five reinforcement materials (Expo, Netlon mesh elements, Pathan, Enkamat, and VHAF) (Baker et al., 1988b). In a study by Baker et al. (1988a), ground cover on the sand root zone was considerably higher than topsoil after initial application of wear.
Table 1. Different types of reinforcement materials that have been evaluated for their influences on playing quality of athletic fields. Two types are generally classified. Horizontal materials are those laid at or near the soil surface. Vertical materials are those mixed or punched into the root zone.

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
<th>Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal Reinforcement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enkamat</td>
<td>Fused nylon threads with 90% open volume, 18 mm thick.</td>
<td>Baker et al., 1988b,c Schmidt, 1982a,b</td>
</tr>
<tr>
<td>Expo 85</td>
<td>Simple mesh with polyester nylon fibers at spacing every 8 and 10 mm, 2 mm thick.</td>
<td>Baker et al., 1988b,c</td>
</tr>
<tr>
<td>Grass-paver block</td>
<td>Concrete block with voids into which grass is grown, used for vehicular traffic</td>
<td>Shearman, 1980</td>
</tr>
<tr>
<td>Pathan 15</td>
<td>Square interlocking tiles (325 mm x 325 mm) molded with openN::esh, 15 mm thick.</td>
<td>Baker et al., 1988b,c</td>
</tr>
<tr>
<td>SportGrass</td>
<td>Matrix of fibrillated fibers tufted into a woven backing into which grass is grown.</td>
<td>McNitt, 2000</td>
</tr>
<tr>
<td>Teconosite</td>
<td>Square interlocking tiles (106 x 106 mm) with internal 8 mm hexagonal and 2 mm circular perforations with studs on the underside, 5 mm thick with 10 mm studs</td>
<td>Baker et al., 1988a;1990a</td>
</tr>
<tr>
<td>Tensar mat</td>
<td>Four layers of polyethylene mesh fused together every 30-35 mm, 15 mm thick</td>
<td>Baker et al., 1988a;1990a</td>
</tr>
<tr>
<td>TS II</td>
<td>Matrix of fibrillated fibers tufted into a dual component backing of biodegradable fibers and a plastic mesh</td>
<td></td>
</tr>
<tr>
<td>VHAF</td>
<td>Needle-punched polypropylene vertical, horizontal and angular fibers, 15 mm thick</td>
<td>Adams and Gibbs, 1989 Baker et al., 1988a,b,c;1990a,b</td>
</tr>
<tr>
<td><strong>Vertical Reinforcement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DD GrassMaster</td>
<td>Narrow polypropylene strands sown vertically into the ground, leaving 2 cm above the top soil</td>
<td></td>
</tr>
<tr>
<td>Dupont Shredded carpet</td>
<td>Shredded carpet strands</td>
<td>McNitt, 2000</td>
</tr>
<tr>
<td>Fibremaster</td>
<td>Fibrillated polypropylene fibers that open into a narrow mesh 40 mm length</td>
<td>Adams, 1997</td>
</tr>
<tr>
<td>Fibresand</td>
<td>Monofilament polypropylene fibers 36 mm length and 113um diam</td>
<td>Baker et al., 1988a;1990a</td>
</tr>
<tr>
<td>Fibresand -straight -crimped</td>
<td>Straight polypropylene fibers 25 mm length and 106 um diam</td>
<td>Baker and Richards, 1995</td>
</tr>
<tr>
<td>Netlon</td>
<td>Rectangular polypropylene mesh elements (105 mm x 50 mm) with spacing every 9 and 11 mm that provide isotropic stabilization</td>
<td>Baker et al., 1988b,c Beard and Sifers, 1989;1990;1993 Canaway, 1994 McNitt, 2000 Richards, 1994 Sifers and Beard, 1996</td>
</tr>
<tr>
<td>Turfgrids</td>
<td>Fibrillated polypropylene fibers that open into a narrow mesh 12 mm to 50 mm in length</td>
<td>McNitt, 2000</td>
</tr>
</tbody>
</table>
Several studies have looked at the effects of wear on ground cover retention for reinforcement material incorporated in soil root zones. Pathan, VHAF, and Enkamat reinforcement materials all improved grass cover in soil (Baker et al., 1988b). After three months of wear, increased grass cover was seen with Pathan on the topsoil root zone (approximately 40%) while the nonreinforced areas had less than 5% (Baker et al., 1988b). Baker et al. (1988b) also found some evidence of improved grass retention with Enkamat on soil when compared to a nonreinforced control but did not see the same response with sand. Tecnotile improved ground cover on topsoil, but, again, this effect was not evident on sand root zones (Baker et al., 1988a). Baker et al. (1988a) found a consistent ranking of materials in relation to ground cover: VHAF (700 g m$^{-3}$) > VHAF (1150 g m$^{-3}$) > Tensar mat > Tecnotile > fiber reinforcement > control (Baker et al., 1988a). In a 1990 study, Baker found that, after simulated wear, ground cover on the topsoil area was significantly higher in plots reinforced with VHAF and that no other reinforcement materials studied differed from nonreinforced plots (Baker, 1990a). Therefore, it seems that VHAF, when used with soil, has been shown to do the most to preserve ground cover.

While the above mentioned studies suggest that few reinforcement materials had a positive effect on ground cover retention in soil, the sand root zone during wear increased ground cover. Baker (1990a) found that ground cover was lost more rapidly from the soil compared to the sand root zone in all reinforcement materials studied. Baker et al. (1988b) found that grass cover subjected to three months of wear was between 45% and 65%, a difference in cover of 15 to 20% when compared to nonreinforced plots. In another study, however, Baker et al. (1988a) found that nonreinforced plots had higher ground cover than reinforced plots near the end of traffic. In a continuation of that study, Baker (1990a) found
no significant differences in ground cover between all reinforcement materials in the sand root zone and the nonreinforced control after two years of traffic.

In a study on the effects of VHAF on ground cover, Baker et al. (1988a) showed evidence of lower grass cover associated with this needle-punched material when used on sand, an opposite effect of what was found on the topsoil as noted above. This was most certainly due to poor grass establishment and methods to improve the establishment have been examined by Adams and Gibbs (1989) with seeding above and below the reinforcement material and by Baker (1990b) with different amendment materials. Baker (1990b) also found that ground cover after wear was better on new plots versus renovated plots of VHAF and that both were better than the nonreinforced control plots. The poorer performance of the renovated plots, which had two previous seasons of wear performed, compared to new plots was most likely due to the buildup of compaction beneath the VHAF and the sealing of the surface layer by organic matter and fine particles transferred from adjacent treatments.

The use of reinforcement materials that are mixed into the root zone (fibers or mesh elements) has been found to be relatively ineffective at maintaining ground cover during traffic when compared to horizontally laid reinforcement materials. Although fiber reinforcement increased surface stability, there was no evidence in the studies by Baker et al. (1988a and 1990a) and Baker and Richards (1995) that the incorporation of fibers into sand increased the retention of grass cover during wear. Similarly, Baker et al. (1988a) found that fiber reinforcement of soil produced more ground cover than nonreinforced plots, however, it ranked considerably lower than horizontally laid reinforcement materials.

Fibermaster incorporated into the root zone did not affect percent ground cover prior to wear simulation (Adams, 1997). After wear, however, a trend of increasing ground cover
with increased fiber incorporation in the top 80mm of root zone was noticed (Adams, 1997). The use of Fibresand was not effective on soil or sand, and there was no evidence in the studies by Baker et al. (1988a) and Baker and Richards (1995) that the incorporation of Fibresand increased the retention of grass cover during wear.

Straight and crimped fibers mixed into sand did not consistently affect grass cover, although crimped fibers had a higher ground cover than straight fibers (Baker and Richards, 1995). For example, on only two of ten dates were there significant differences in ground cover attributed to incorporation rate or fiber type (Baker and Richards, 1995). The highest rates of fiber incorporation had less ground cover than the control with no reinforcement (Baker and Richards, 1995).

**Divots**

Beard and Sifers (1989; 1990; 1993) found that the presence of Netlon mesh elements reduced the size of divots and that divot scars recovered at a faster rate. Using their 1989 data, they found that divot length and width were 121 mm and 48 mm where no reinforcement was used but only 75 mm and 42 mm when mesh elements were incorporated in the root zone. In another study, Sifers and Beard (1996) found that the inclusion of mesh elements in sand, sandy clay loam, and clay loam decreased divot length by 24 to 49% and reduced divot width by 14 to 22%. The turf recovery period of these divot openings was 29 to 41% faster than the nonreinforced control (Sifers and Beard, 1996).

Adams (1997) found that damage to turf through divoting was reduced by incorporation of Fibermaster fibers. As levels of fiber incorporation increased, divot length significantly decreased.
Roots

Rooting is essential for the stability of the grass surface, and has thus received much study. Adams et al. (1985) showed that 65% of variation in traction could be accounted for by the amount of roots in the top 2 cm of the surface, but roots at depths greater than 2 cm did not improve traction. Gibbs et al. (1989) stated that changes in surface stability, as estimated by traction, could be accounted for by changes in root organic matter.

Adams and Gibbs (1989) found root weight below a layer of VHAF was reduced by 33% when compared to a control at a depth of 4.5 cm to 9.0 cm. Seeding above and below the VHAF helped alleviate the problem by doubling the amount of dry root weight below the material (Adams and Gibbs, 1989).

Adams (1997) focused on the effects of Fibermaster fibers incorporated into the top 100 mm of sand root zones on rooting ability. Fibers increased shear resistance when turfgrass roots were present and absent (Adams, 1997). At the 0.2% incorporation rate of fibers, shear resistance was over three times greater in sand with roots present than pure sand (Adams, 1997). Turfgrass roots also increased stability. Although there was a positive interaction between the fibers and the turfgrass roots, the presence of fibers did not increase the amount of roots produced. Instead, the fibers helped increase the effectiveness of the roots that were already present (Adams, 1997). In this study, however, penetration resistance increased logarithmically with an increase in fiber incorporation, making it harder for roots to penetrate through the sand (Adams, 1997). Therefore, there is an optimal level of fiber incorporation that is a trade off between root stability and root penetration. Beard and Sifers (1993) also found that root development on bermudagrass was greater when Netlon mesh elements were present and there was evidence of greater dry matter production occurring on
the mesh inclusion turf than the no mesh treatment turf. Addition of reinforcement materials may compromise root growth and development, however, the stability gained by these reinforcement materials is very beneficial for player performance.

*Water Infiltration Rate*

Water infiltration is the movement of water into the root zone. Low water infiltration rates can lead to standing water on the turf's surface (surface ponding) and eventually to surface stability problems. In studies conducted by Baker et al. (1988a,b), surface ponding occurred more frequently on soil plots than sand plots since the finer particles of soil easily clog the pores in the reinforcement material. The use of VHAF, Pathan, Enkamat, Tecnotile, and Tensar mat reduced the incidence of ponding when compared to a nonreinforced control (Baker et al., 1988a,b). For example, Baker et al. (1988a) recorded surface ponding on VHAF (1150 g m⁻³) on 3 days and VHAF (700 g m⁻³) on 6 days while the control had 32 days of surface ponding. During the second year of the Baker et al. (1988a) study, however, the incidence of ponding increased on both the sand and soil for all the treatments (Baker, 1990a). In this year, water infiltration rates were so low for the control on soil that over 50% of the assessment dates had surface ponding. Baker (1990a) believed the increase was due to either surface sealing of the geotextile or increased soil compaction below the reinforcement material, and he found that reinforcement materials were not effective in reducing soil compaction. In another study, Baker (1990b) showed that surface ponding occurred more frequently on areas with no reinforcement versus those with reinforcement (VHAF at 700 and 1150 g m⁻³). Water infiltration rates were improved significantly on newly constructed plots with VHAF compared to renovated plots with VHAF (Baker, 1990b).
Several studies have evaluated the effects of Netlon mesh elements on infiltration rates in turf, focusing on variations in element size, incorporation rate, and inclusion depth. Studies have shown increased infiltration rates associated with the inclusion of mesh elements (e.g. Beard and Sifers, 1993; Canaway, 1994; Richards, 1994; and Sifers and Beard, 1996). Sifers and Beard (1996) found that the inclusion of mesh elements to the root zone improved infiltration rates 47% in sand and 93% in clay loam. In contrast, Baker et al. (1988b) found that Netlon mesh elements were not effective in reducing surface ponding.

Using micromorphological, thin-section analysis, Beard and Sifers (1993) found voids around certain areas of mesh strands and hypothesized that under traffic pressures, the mesh element matrix may actually be flexing slightly in a microcultivation type soil action. This could contribute to the observed increased infiltration with the use of mesh elements.

Porosity

There are two types of porosity of interest for soils in athletic fields: total porosity and air-filled porosity (Danielson and Sutherland, 1986). Total porosity is the fraction of soil volume not occupied by solids. Air-filled porosity is the portion of the total porosity that is filled with air and not water. A reduction in porosity can lead to a reduced water and air holding capacity of the soil. This in turn can negatively affect the turf.

Air-filled and total porosity for the soil area resulted in no significant differences between reinforced and nonreinforced treatments (Baker et al., 1988b). On the sand area, however, control plots had the lowest total porosity and air-filled porosity while the incorporation of Pathan and Enkamat increased total porosity and air-filled porosity (Baker et al., 1988b).
Studies by Baker et al. (1988a) and Baker and Richards (1995) showed that the incorporation of fibers had a significant effect on soil physical properties. As fiber content increased from zero to 0.75%, total porosity and air-filled porosity at -4 kPa moisture both increased (Baker and Richards, 1995).

*Surface Hardness*

Surface hardness is a term that characterizes the impact energy created between the player and surface that relate to player performance (Baker and Canaway, 1993). Measurements of surface hardness or cushioning properties of turf depend on several assumptions (Nigg, 1990). Perhaps the most important is that values of impact forces, deceleration, and deformation are highly dependent on the drop mass, drop height, and the area of contact with the surface. The most common method of measurement for surface hardness on natural turf has been the Clegg Impact Soil Tester (Clegg, 1976). Peak deceleration ($g_{max}$) of a 0.5-kg hammer dropped from 0.3 m has been shown to correlate well with player perception of surface hardness when both running and falling/diving onto the surface (Canaway et al., 1990). Proposed minimum and maximum standards for surface hardness by Canaway et al. (1990) were preferred to be between 20 and 80 g and acceptable between 10 and 100 g.

Baker et al. (1988c) found that, in general, reinforced treatments were harder than nonreinforced treatments on sand. Tecnotile produced the hardest conditions on both sand and soil, especially during dry conditions (Baker et al., 1988a). For soil, the use of Pathan and VHAF led to a firm surface during both dry and wet conditions (Baker et al., 1988c).
Baker et al. (1988a) concluded that the effects of the fibers on surface hardness were generally small, although there was some evidence of increased firmness on the sand construction. Baker and Richards (1995) incorporated different rates of fibers and found a significant increase in surface hardness. In fact, as the rate of fiber inclusion increased, the surface tended to become harder (Baker and Richards, 1995). There was some evidence that at the end of the playing season, when conditions were dry, the fibers were making the surface slightly harder than the optimum range, and Baker and Richards (1995) noted that careful control of irrigation was needed to control this effect. There was also some evidence from the hardness data that straight fibers gave a firmer surface than crimped ones but this was only significant on four of the eleven assessment dates (Baker and Richards, 1995).

Beard and Sifers (1993) found some reduction in hardness as the element inclusion rate of Netlon increased from zero to 5 kg m⁻³, while Canaway (1994) found small but significant increases in hardness values. Beard and Sifers (1993) made their measurements under relatively firm ground conditions, while Canaway (1994) made his while the turf was soft or, in one case, very soft. Although the discrepancy in results may arise from differences in grass species, climate, or turf management, it may also be that the mesh elements can in part moderate both extremes of hardness and softness.

Traction

Traction can be described as the property that enables a player to make the necessary movements in sports without excessive slipping or falling. The term traction applies to footwear equipped with cleats or spikes that provide improved grip (Baker and Canaway,
Although no maximum standard has been proposed for traction, minimum standards are preferred to be 25 N·m and acceptable at 20 N·m (Canaway et al., 1990).

Traction has been one of the most widely studied aspects of playing quality. For natural turf the standard apparatus used is a studded disc loaded with weight that was developed by Canaway and Bell (1986). However, this device only measures a rotational traction instead of a more dynamic traction measurement as experienced by players. Nigg (1990) expressed several problems associated with traction measurements. Firstly, the characteristics of traction depend on both the properties of the footwear as well as the surface. Secondly, it is necessary to consider both the rotational and transitional movements. Thirdly, the normal force can have a major influence on the test results because players make subtle adjustments in foot position and weight distribution depending on the type of footing required. Although not theoretically ideal, the existing measurements do provide a simple method to test the traction of a playing surface. Test to determine the traction will improve once the equipment can more closely simulate the stud patterns, velocities, and applied forces of actual players.

Baker et al. (1988c) found that traction was higher for Expo and Enkamat than the nonreinforced control on both sand and soil. These values were considered excessively high and resulted when the cleats became entangled in the reinforcement materials (Baker et al., 1988c). Although Baker et al. (1988c) expressed concern for player safety, especially knee and ankle injuries, there has been no upper limit established for traction in natural turf (Canaway et al., 1990). During the wettest dates, VHAF and Pathan used on soil also produced significantly higher traction values than the control, whereas no other reinforcement materials produced significantly higher traction values on the sand carpet.
(Baker et al., 1988c). Similarly, Baker et al. (1988a) found no differences in traction on sand with VHAF and Tecnotile when compared to the nonreinforced control (Baker et al., 1988a). Tecnotile did not allow penetration of cleats, which explains its low traction values (Baker et al., 1988a). In the same study, Tensar mat consistently gave the highest traction values on soil, while also produced significantly higher traction values (Baker et al., 1988a). Prior to wear, the poor establishment of VHAF led to lower traction values than the control, but, as wear progressed, these values became higher than the control (Baker et al., 1988a). Adams and Gibbs (1989) found that VHAF helped maintain traction properties on intensively worn areas for sand root zones. Traction properties were also improved using VHAF on topsoil areas, but in the absence of ground cover, traction fell to unacceptable levels.

Baker and Richards (1995) studied the effects of fiber reinforcement on traction. Before grass establishment in the study area, traction values averaged 11.8 N·m where no fibers were present and 17.2 N·m at a fiber incorporation rate of 0.75%. In dry conditions, at the end of the trial when the remaining grass cover had been killed by paraquat, traction values averaged only 15.6 N·m on the nonreinforced sand but 20.7 N·m at the 0.75% rate. Baker and Richards (1995) did not find any significant differences in traction between straight and crimped fibers. Adams and Gibbs (1994), however, showed inclusion of fibrillated fibers mixed with sand can increase shear resistance.

With respect to traction, Baker et al. (1988c) found no significant effects of Netlon mesh element incorporation in the upper 100 mm of the topsoil and sand carpet areas. Beard and Sifers (1993) found that traction varied in response to the incorporation of Netlon. On the other hand, Canaway (1994) found, after seven months of soccer-type wear, that traction significantly increased as the mesh element rate increased from zero to 5 kg m⁻³.
Ball Rebound and Ball Roll

Another factor of playing quality is the interaction between a ball and the surface. Surfaces that are wet tend to decrease ball characteristics while dry surfaces tend to increase ball characteristics. There are two types of measurements: ball rebound resilience and ball roll. Ball rebound resilience is expressed as the ratio or percentage of height bounced to height dropped (Baker and Canaway, 1993). Preferred limits between 20% and 50% and acceptable limits between 15% and 55% have been proposed as the minimum and maximum standards for ball rebound resilience (Canaway et al., 1990). Ball roll resistance is the deceleration of the ball as it moves across the surface and is expressed as distance rolled (Baker and Canaway, 1993). The minimum and maximum standards proposed by Canaway et al. (1990) for distance rolled has preferred limits between 3 and 12 m and acceptable limits between 2 and 14 m. For both the ball rebound and ball roll tests, the soccer ball used must be inflated to 0.7 bar and rebound between 57% and 59% on concrete (Canaway et al., 1990).

During wear, ball rebound for the Pathan and VHAF remained consistent on the soil root zone whereas it dropped below 20% for the control, Netlon, Expo, and Enkamat plots (Baker et al., 1988c). During wet weather, ball rebound resilience on soil was low on the control plots (< 2%) as well as on plots mixed with fibers. On sand, ball rebound ranged between 30-45%, and Pathan maintained the highest ball rebound throughout the duration of the study, often exceeding 46% (Baker et al., 1988c). In another study, however, Tecnotile gave the highest values with increased wear (41 to 47%) and VHAF (1150 g m⁻³) gave the lowest (32-38%) (Baker et al., 1988a). Ball rebound resilience tended to increase as fiber content in the root zone increased (Baker and Richards, 1995). On 8 out of 11 dates significant differences in ball rebound resilience for different fiber rates were recorded.
Differences were most noticeable before traffic when ball rebound resilience in nonreinforced plots was 27.4% and over 35% for all the reinforced plots (Baker and Richards, 1995). Neither Beard and Sifers (1993) nor Canaway (1994) found any effect of Netlon mesh elements on the overall height of ball rebound but, Beard and Sifers (1993) reported improved uniformity of ball bounce.

In general, the effects of the reinforcement materials on ball roll were small. On the other hand, ball roll was related to the soil moisture conditions. Surfaces were faster and rolled farther when dry than when wet (Baker et al., 1988a). For example, in December, wet, muddy conditions caused the ball to stop rapidly for control and fiber reinforced plots. Sand provided more consistent conditions throughout the study, including wet months, than did the topsoil plots (Baker et al., 1988a). After renovation, reinforced plots of VHAF failed to meet the acceptable limit of 15% set by Canaway et al. (1990) while the newly constructed plots were 18.8% and 20% (Baker, 1990b). Renovated plots were more likely to be compacted, holding more moisture, and therefore decreasing ball roll.

**Conclusion**

The use of reinforcement materials in turfgrass is still a relatively new management technique, and their intended purpose is to provide stability on the playing field. Several studies have focused on the various reinforcement materials available on the market and their effects on the playing quality of natural turf fields. In general, reinforcement materials seem to help improve playing quality, while few results have shown that playing quality is actually diminished in their presence. Not all reinforcement materials perform the same functions and
their effectiveness in improving playing quality depends on which aspects a manager intends to improve.

Compared to nonreinforced controls, reinforcement materials laid horizontally at or near the soil surface improved ground cover during wear and were more effective on sand than soil. The use of reinforcement materials that are mixed into the root was found to be relatively ineffective at maintaining ground cover during wear. The use of reinforcement materials was shown to be effective at reducing the size of divots removed from the turf surface. Studies have also shown that root growth and development may be compromised by the addition of reinforcement materials, and this, in turn, could reduce surface stability. Water infiltration rates improved with the incorporation of reinforcement materials, and the incidence of surface ponding occurred more frequently on soil plots than sand plots. Porosity was affected both positively and negatively by the use of reinforcement materials. With the use of both horizontal and mixed reinforcement materials, the surface was harder than when compared to nonreinforced controls. Results regarding traction have been equivocal for the many types of reinforcements, but, in general, soil produced higher traction than sand for most reinforcement materials. Ball rebound and ball roll improved with the use of reinforcement materials on sand but not as effective on soil compared to nonreinforced controls.

There is a need for long-term research on the playing quality of fields using reinforcement materials, as the use of certain practices may be detrimental to the reinforcement material over several years of wear or the effectiveness of certain materials may not become evident until significant wear has even occurred. However, several short-term studies have demonstrated that the use of reinforcement materials is beneficial,
especially in high wear areas. Their cost effectiveness, when compared to turf renovation or repair and compromised playing conditions, makes them an even more attractive approach to turfgrass management.
CHAPTER 3. MANAGEMENT OF SPORTGRASS FOR ATHLETIC FIELDS

A manuscript to be submitted to Crop Science

Jay S. Hudson and David D. Minner

ABSTRACT

Sand-based root zones promote rapid drainage and reduce compaction, but athletic playing surfaces may become unstable when exposed to intense wear. SportGrass, a hybrid reinforcement system comprised of a sand-filled synthetic matrix in which grass is grown, is the first product that claims to combine the playability of natural grass with the durability of synthetic turf. Our objective was to determine what effect conventional turfgrass management practices have on the stability and quality of the playing surface of a SportGrass system. A study area was established in 1996 using ‘Limousine’ Kentucky bluegrass (Poa pratensis L.). Simulated wear treatments were conducted during the spring and fall playing seasons, and turf was allowed to recover during the summer and winter. Surface hardness, traction, percent cover, and turf quality were measured following spring and fall traffic and recovery periods in both 1998 and 2000. Saturated hydraulic conductivity, system bulk density, and dry root mass were measured before and after fall traffic in 1999. Prior to the beginning of the study, surface hardness for the control with SportGrass (73 g) was harder than the seeded and sodded controls without SportGrass (57 and 52 g). This trend continued throughout the study. Vertical mowing significantly increased gmax from 76 to 94 g on 4 May 1998 and from 84 to 97 g on 6 May 1999. Solid tine aerification of SportGrass reduced gmax from 90 to 66 g on 25 Aug. 1998 and from 96 to 80 g on 25 Aug. 1999. Traction recorded after fall recovery in year one was high (> 84 N·m for all treatments with
SportGrass). Turf cover and turf quality were greater for treatments with SportGrass than without SportGrass on all dates following spring traffic in Year 1. Dry root mass was greater for treatments without SportGrass. Saturated hydraulic conductivity for treatments with SportGrass ranged from 25 to 29 cm hr\(^{-1}\) while treatments without SportGrass were 16 cm hr\(^{-1}\) for seeded and 9 cm hr\(^{-1}\) for sodded. Seeded and sodded without SportGrass (1.59 and 1.60 g cm\(^{-3}\)) had higher system bulk densities than all treatments with SportGrass. The SportGrass system produced a more stable playing surface compared to nonreinforced sand-based systems.

**Additional Index Words.** traction, surface hardness, sand root zone, traffic, soil physical properties, Kentucky bluegrass

**INTRODUCTION**

Sand-based systems are used widely for natural-grass athletic fields. Sand promotes rapid drainage of the root zone and provides good aeration (Baker, 1988). This results in better retention of ground cover (Baker and Canaway, 1990) and provides good playing quality (Baker and Isaac, 1987). Playing quality of athletic fields can be identified by two different but related interactions between the surface and player, and between the surface and ball (Bell et al., 1985; Canaway, 1985). Interactions between the surface and player include surface hardness and traction. Surface hardness is defined as the effect the surface has on absorbing impact energy created by a player (Bell et al., 1985). Fields that are hard can be dangerous to players, while a soft, spongy field can create early fatigue in the leg muscles of a player. Traction is defined as the type of footing a playing surface provides (Bell et al.,
A wet field with little ground cover offers little traction and may cause players to slip and fall. Similarly, uneven, bumpy, sparsely covered playing surfaces can cause the ball bounce and roll to be unpredictable and can also adversely affect footing. Maximizing turf cover and vegetative mat also maximizes player performance by allowing players to control their movements. Reducing turf cover therefore limits a players ability to produce controlled movements. Limiting a players control inherently increases risk of injury. Player safety and player performance is most jeopardized during high usage of sand-based systems when the grass has worn away, allowing the surface to become exposed and unstable (Holmes and Bell, 1986).

On sand-based systems, root growth is essential for holding the playing surface together (Gibbs et al., 1989). To support root growth, several reinforcement materials have been developed. These materials are intended to stabilize sand-based root zones and extend the durability of athletic fields without compromising player performance and safety. Many researchers have examined the effects of reinforcement materials. Baker et al. (1988a,b,c) and Baker (1990a) tested several materials, including plastic tiles, two- and three-dimensional meshes, fibers, and mesh elements. Baker (1990b) and Adams and Gibbs (1989) considered the effect of a needle-punched geotextile. Isotropic reinforcement by using elements of mesh materials mixed within sand root zones has been described by Beard and Sifers (1989; 1990; 1993), Canaway (1994), and Richards (1994). Adams and Gibbs (1994) showed inclusion of fibrillated fibers mixed with sand can increase shear resistance.

SportGrass is the first product that combines the playability of natural grass with some of the more durable characteristics of synthetic turf (SportGrass Athletic Surfacing, 2000). The SportGrass system is a synthetically reinforced layer of grass that is grown on a
sand-based root zone. The system consists of grass grown into a synthetic matrix of fibrillated fibers (polypropylene blades) tufted into a woven backing. Because SportGrass is a relatively new innovation in turf management, there is little quantitative evidence that lends support to its proposed benefits as a reinforcement material. McNitt (2000) examined several soil reinforcement materials and showed that SportGrass reduced divot length and soil water content but increased surface hardness when compared to a nonreinforced control.

In our study the stability and quality of a reinforced system, SportGrass, was compared to a nonreinforced playing surfaces. The objectives were to: 1) evaluate the playing quality, in terms of surface hardness, traction, percent cover, and turf quality, of SportGrass when subjected to conventional turfgrass management practices such as vertical mowing, solid tine aerification, and plant growth regulator; 2) to compare turfgrass reinforced with SportGrass to turfgrass without SportGrass that was established by seed and sod, and; 3) to determine whether saturated hydraulic conductivity, dry bulk density, and root dry weight were affected by the SportGrass system.

MATERIALS AND METHODS

The study area was established in Sept. 1996 with 'Limousine' Kentucky bluegrass (Poa pratensis L.) at the Iowa State University Horticulture Research Station, 16 km north of Ames, Iowa. The modified root zone consisted of 99% sand and 1% Dakota Peat (Dakota Peat and Blenders, Grand Forks, ND) by weight that met specifications of the United States Golf Association (USGA, 1993). The study included four treatments with SportGrass (control, vertical mowing, solid tine aerification, and plant growth regulator), and two treatments without SportGrass (seeded and sodded). The synthetic matrix of the SportGrass
system is comprised of fibrillated fibers (8000 denier polypropylene) that are needle-punched into a 12 pique polypropylene woven backing at a stitch rate of 11 stitches per 7.5 cm. Stitch rows were produced from needles on 1.0-cm centers and the fibrillated fibers were trimmed to 3.2 cm in length (SportGrass Inc., McLean, VA). The treatments were arranged in a randomized complete block design, with each treatment having three replications. Individual plots were 1.8 m by 6.1 m.

A Brouwer traffic simulator (Brouwer Co., Dalton, OH), developed by R.N. Carrow (personal communication, 1996), was used to supply differential slip-type traffic on 0.3-m centers across the plots. The modified, double-roller, traffic simulator was equipped with 1.5-cm football cleats. The width of each roller was 0.6 m. Traffic was applied to all treatments to simulate spring and fall playing seasons with a no-traffic recovery period during the summer and winter. A pass consisted of driving the simulator down the length of the overall plot. During 1998, spring traffic was applied from 21 May to 30 June (48 passes) and fall traffic was applied from 9 Sept. to 28 Oct. (133 passes). In 1999, spring traffic was applied from 7 May to 16 June (54 passes) and fall traffic was applied from 16 Sept. to 30 Nov. (196 passes). Therefore, spring recovery is the recovery of plots from spring traffic and assessed following the summer, and fall recovery is the recovery of plots from fall traffic and assessed following the winter.

Vertical mowing was performed on 4 May 1998, and 6 May 1999. A Bluebird vertical mower set at a 1.2-cm depth (even with the top of the synthetic grass blades) was used to make two passes over each plot at 90°. Thatch litter was raked and removed from the surface. Solid tine aerification were applied on 4 May, and 25 Aug. 1998, and on 6 May, and 25 Aug. 1999. A GA30 Cushman aerifier (Textron Inc., Racine, WI) with solid 1.0-cm tines
was used to punch holes on 5.0-cm centers at 387 holes m⁻². Data were collected before and after vertical mowing and aerification treatments were applied. Applications of Primo 1EC (Trinexapac-ethyl) was applied at 0.289 kg a.i. ha⁻¹ with a CO₂ sprayer on 23 May, 27 June, and 29 July 1998, and 20 May, 28 June, and 27 July 1999.

The plots were evaluated prior to the beginning of the study and following traffic and recovery periods for surface hardness, traction, quality, and cover. Data were collected in Year 1 on 4 May, 25 Aug., 29 Oct. 1998, and 6 May 1999, and in Year 2 on 14 June, 25 Aug., 7 Dec. 1999, and 13 May 2000. During Year 2, additional evaluations were taken before and after traffic on saturated hydraulic conductivity, system bulk density, and dry root mass.

**Surface Hardness and Soil Moisture**

Surface hardness was measured using a portable drop-hammer apparatus described by Rogers and Waddington (1990). A cylindrical hammer, with a mass of 2.25-kg, a diameter of 5 cm and, a length of 67 cm, was dropped from a height of 45.5 cm through a polyvinyl chloride tube (5.5 cm in diameter and 60 cm in length). A Brüel and Kjaer accelerometer (Model #4393-1639904) (Brüel and Kjaer, Decatur, GA) attached to the hammer measured the negative acceleration (deceleration) in gravities (g = acceleration due to gravity) caused by impact with the surface. A Brüel and Kjaer 2515 Vibration Analyzer (B&K) was used to record the impact measurements generated from the accelerometer. A harder, less resilient surface is indicated by a higher g_max (peak deceleration) value. Five individual drops were taken in different locations within each plot, averaged, and stored in the B&K. Gravimetric soil moisture (Gardner, 1986) was measured each time hardness was measured. Soil cores
were randomly sampled from the SportGrass control and seeded control to a depth of 10 cm. The thatch or vegetative mat and synthetic material were removed from the soil cores. Soil moisture was determined from the 5-10 cm region of the core that was located below the synthetic backing of the SportGrass system.

**Traction**

Traction measurements, recorded in torque (N·m) (N = newton; N·m, SI units for torque) were taken with a studded torque wrench device, developed by Canaway and Bell (1986). The apparatus was equipped with 45-kg of weight and dropped from a height of 5 cm. Traction was estimated as the amount of torque required to tear the underlying sod. Two traction assessments were made within each individual plot.

**Quality and Cover**

Turfgrass quality was evaluated on a 1-9 scale; 1 represented the worst, 9 represented the best, and 5 represented minimally acceptable turf. Turf quality is an overall visual rating of turf density, color, and texture. Turf density and retention of a vegetative mat or thatch were given more consideration than color and texture when rating turf quality of treatments receiving traffic in this experiment. Turfgrass cover was visually estimated as the percentage of each plot covered by living turf. Percent living turfgrass cover is probably the most important parameter in terms of evaluating the detrimental effects of traffic on athletic turf. Following traffic treatments, turf begins to decline and the underlying materials become visible. Treatments with a high percentage of turf cover are more desirable. Traffic
tolerance was assessed by visually rating quality and estimating percent living turfgrass cover.

**Dry Root Mass**

Root mass was measured at three different zones, above the synthetic matrix (0 to 2 cm), within the synthetic matrix (2 to 5 cm), and immediately below the synthetic matrix (5 to 17 cm). Two soil cores per plot, 10.8 cm in diameter by 17.0 cm in length, were taken before traffic on 8 Sept. 1999 and after traffic on 6 Dec. 1999. Cuts were made at 2 cm and 5 cm to section each soil core. Sand, peat, and roots were placed in a water-filled pan, and floating roots were removed. The remaining material was poured through a 2-mm screen into a 53-μm screen. Roots caught by the 2-mm screen were removed. The material on the 53-μm screen was removed and placed again in the catch pan. The catch pan was filled with water, and the material was poured back through the 2-mm screen. This screening process was done three times for each soil core. Washed roots were dried in an oven at 67°C for 48 h, and oven-dry mass was recorded. Roots were ashed at 500°C for 12 h to remove C from each root sample. The final root mass was determined by subtracting the ashed root mass from the oven-dry root mass. This was done to insure that no mineral soil was being weighed in the root samples.

**Saturated Hydraulic Conductivity and System Bulk Density**

Two undisturbed soil samples per plot were taken before traffic on 7 Sept. 1999 and after traffic on 5 Dec. 1999 with an AMS Core Soil Sampler (AMS, American Falls, ID). Soil cores were 4.8 cm in diameter by 15.3 cm in length and included the vegetative mat or
thatch layer near the soil surface. Soil cores taken from treatments with SportGrass contained the synthetic matrix. Saturated hydraulic conductivity ($K_{sat}$) and system bulk density ($D_b$) were determined in the laboratory using ANSI-ASTM method F 1815-97 (ASTM, 1998).

**Statistical Analysis**

Data were analyzed by using the Analysis of Variance (ANOVA) procedure of Statistical Analysis System (SAS Institute, 1996). Fisher’s least significant difference (LSD) tests was used to compare treatment means. Statistical significance was determined at $P \leq 0.05$.

**RESULTS**

**Surface Hardness**

Prior to the beginning of the study, surface hardness for the control with SportGrass (73.0 g) was harder than the seeded and sodded controls without SportGrass (56.8 and 52.0 g) (Table 1). On all remaining observation dates, similar results occurred with the SportGrass control being harder than the seeded and sodded controls. Vertical mowing, solid tine aerification, and plant growth regulator all significantly increased surface hardness compared to the sodded treatments on 7 observation dates. Vertical mowing and plant growth regulator significantly increased surface hardness on 7 and 6 observation dates, respectively, compared to the seeded treatment, while solid tine aerification produced harder surfaces on only 4 observation dates. SportGrass control produced harder surfaces than solid tine aerification on 5 observation dates, but was similar to vertical mowing on all dates.
except after fall traffic in Year 1 and after spring traffic in Year 2 (Table 1). The only observation date where SportGrass control (96.6 g) produced a harder surface than plant growth regulator (90.4 g) occurred in Year 2 after fall traffic (Table 1). Furthermore, plant growth regulator was not different than vertical mowing on all observation dates except after fall traffic in Year 1. Solid tine aerification reduced surface hardness compared to vertical mowing and plant growth regulation on 5 and 3 observation dates, respectively. During the study, the seeded control was significantly harder than the sodded control on 5 observation dates.

To determine the immediate affect that vertical mowing and solid tine aerification had on the SportGrass system measurements were taken immediately before and after treatment. Vertical mowing and aerification immediately changed surface hardness. Vertical mowing significantly increased $g_{\text{max}}$ from 75.7 to 94.3 g on 4 May 1998 and from 83.9 to 94.4 g on 6 May 1999 (Table 5). Solid tine aerification of SportGrass significantly reduced $g_{\text{max}}$ from 89.6 to 66.2 on 25 Aug. 1998, from 75.8 to 61.4 g on 6 May 1999, and from 96.0 to 80.2 g on 25 Aug. 1999. (Table 5).

**Traction**

At the beginning of the study and prior to any traffic there were no differences in traction. On 5 of the 7 observation dates remaining, there were differences among treatments. In Year 1 after fall recovery, all treatments with SportGrass produced greater traction than the seeded control (Table 2). In both Year 1 and Year 2, no significant differences resulted after fall traffic between treatments with SportGrass and sodded control but after fall recovery all treatments with SportGrass produced greater traction than the
sodded control. Traction recorded after fall recovery in Year 1 was unusually high (> 84 N·m for all treatments with SportGrass) (Table 2). The SportGrass control produced greater traction than the seeded or sodded control on 3 and 4 observation dates, respectively. Plant growth regulation produced greater traction than the seeded or sodded control on 4 and 3 observation dates, respectively. After fall recovery in Year 1 the SportGrass control (87.7 N·m) produced greater traction than vertical mowing (93.7 N·m) but results were reversed on the next two observation dates; after spring traffic and after spring recovery (control 72.8 and 64.2 N·m and vertical mowing 62.5 and 57.0 N·m, respectively) (Table 2). Control with SportGrass was similar to solid tine aerification on all observation dates and plant growth regulator on six observation dates. After the fall recovery periods in both years, seeded control had greater traction than sodded control, while after fall traffic in Year 1 sodded control had more traction than the seeded control.

**Quality and Cover**

Before traffic and after spring recovery in Year 1, there were no treatment effects on turf quality. On the remaining 6 observation dates all treatments with SportGrass had better turf quality than the seeded and sodded treatments without SportGrass (Table 3). After Year 1 fall traffic sodded without SportGrass fell below the minimally acceptable level of 5.0 and was above the acceptable level only after spring traffic in Year 2. Turf quality ratings were higher for plant growth regulator than the control with SportGrass after fall traffic and recovery in Year 1 and after spring traffic and recovery in Year 2 (Table 3). Turf quality was similar for control with SportGrass, vertical mowing, and solid tine aerification except for after spring recovery in Year 2 (7.3 for control, 8.0 for vertical mowing, and 8.0 for solid tine
aerification). Turf quality for vertical mowing and solid tine aerification were similar during the entire study.

Percent cover was the same for all treatments prior to application of traffic (all treatments = 99%). On all of the remaining dates treatments with SportGrass had higher percent turf cover than the seeded and sodded treatments without SportGrass (Table 4). After fall recovery in Year 1 seeded had a higher percent turf cover than sodded and that difference was maintained during all the remaining observation dates. No differences in percent turf cover were recorded for all treatments with SportGrass.

**Dry Root Mass**

Root dry weight above the synthetic matrix for sodded control (7.53 g) was significantly lower than the seeded control (11.01 g) (Table 6). Root dry weight for all treatments with SportGrass were higher than the sodded control. Within the synthetic matrix zone, the seeded and sodded treatments (1.45 g and 1.34 g) were higher than all the treatments with SportGrass. No differences were seen in root dry weight between all the SportGrass treatments above the synthetic matrix and within the synthetic matrix (Table 6). Below the synthetic matrix, root dry weight for the seeded control (1.52 g) was significantly higher than the SportGrass control (1.12 g) (Table 6). Solid tine aerification had greater root weight below the synthetic matrix than vertical mowing. Below the synthetic matrix, solid tine aerification was similar in root weight to the seeded control. Below the synthetic matrix, root dry weight for the sodded control after traffic was nearly half the amount as before traffic and this could have been due to samples taken from areas infected with Summer Patch
(Magnaporthe poae). Because of this error, below the synthetic matrix had a wear by treatment interaction.

Saturated Hydraulic Conductivity and System Bulk Density

Sodded control (8.9 cm hr$^{-1}$) had a significantly lower $K_{sat}$ than the seeded control (16.4 cm hr$^{-1}$). Both of these treatments were significantly lower than all treatments containing SportGrass treatments (range from 25.1 to 28.9 cm hr$^{-1}$) (Table 7). Vertical mowing reduced $K_{sat}$ compared to all other treatments with SportGrass. Although wear reduced $K_{sat}$ for all treatments, there was no wear by treatment interaction.

Seeded and sodded without SportGrass (1.59 and 1.60 g cm$^{-3}$) had higher bulk densities than all treatments with SportGrass. Bulk density for solid tine aerification (1.52 g cm$^{-3}$) was lower than all of the other treatments with SportGrass (Table 7). The effects of traffic increased bulk density for all the treatments but there was no wear by treatment interaction.

DISCUSSION

The addition of SportGrass as a reinforcement material increased surface hardness when compared to the seeded and sodded controls without SportGrass. This increase was apparent from the beginning of the study, even before simulated traffic was applied. Similar increases have been seen with the addition of reinforcement materials by several researchers. Increased rate of fiber incorporation caused increases in surface hardness from 32.9 to 35.4 g (Baker and Richards, 1995). Other results of surface hardness with Netlon mesh elements
have been contradictory; Beard and Sifers (1993) found reduced surface hardness with increased elements while Carraway (1994) found increases with increased mesh elements.

Management practices that influence soil water content, soil compaction, and turf cover also influence surface hardness (Roger and Waddington, 1992). In this study, reducing the mat above the SportGrass synthetic fiber with vertical mowing increased \( g_{\text{max}} \), while solid tine aerification reduced \( g_{\text{max}} \) in the SportGrass system. Solid tine aerification reduced \( g_{\text{max}} \) to a level similar to the nonreinforced seeded control. Aerification is a management practice that can be used to regulate surface hardness in a SportGrass system. The recovery period following fall traffic was 5 to 6 months in length and occurred during the winter. The subsequent freezing and thawing was very beneficial in reducing the surface hardness for all treatments, however the application of traffic resulted in progressively higher \( g_{\text{max}} \) each year.

On only five of the observation dates was there a significant difference for traction among treatments. During these dates, SportGrass control and plant growth regulator, resulted in higher traction values than the control seeded and sodded. On one occasion though, after fall traffic in Year 1, traction values for plots reinforced with SportGrass were very high (> 84 N·m ) and significantly higher than seeded and sodded treatments. Traction for all treatments in this study was greater than the preferred minimum of 25 N·m suggested by Carraway et al. (1990). Since there is no defined upper limit for traction on natural turf, it is not known if the measured traction of 84 N·m poses any risk to players. Desired shoe traction on synthetic turf should have a coefficient of friction between 0.8 and 1.2 (Breland, 1996). Greater traction associated with SportGrass was likely caused by cleat penetration into the fibrillated fibers. The cleats locked against the stabilizing fibers causing greater
traction. Similarly, studies involving reinforcement material showed increased traction when
reinforcement materials were used as a stabilizer (Baker 1990a; 1990b; Adams and Gibbs,
1994). Reinforcement materials have proved effective on intensively worn areas with sand

Turf cover and turf quality were greater for treatments reinforced with SportGrass
than without SportGrass on all dates following the first application of wear. Turf quality
without reinforcement fell below the minimally acceptable level for playing conditions.
Simulated traffic on the unacceptable plots resulted in the turf cover being torn and ripped
away which then exposed the underlying sand. Baker (1990a; 1990b) found evidence of
improved grass retention on a topsoil root zone with the use of reinforcement, but the similar
responses were not evident on sand root zones, which was perhaps due to poor grass
establishment.

The SportGrass system increased $K_{sat}$ and decreased system $D_b$ compared to the
nonreinforced plots. Although differences were seen before and after wear on all treatments,
there was no wear by treatment interaction observed. This suggests that the synthetic matrix
of SportGrass provided macropores for water to move through the profile. Baker and
Richards (1995) showed as fiber content increased so did the hydraulic conductivity. The
sodded control had a lower $K_{sat}$ than the seeded control. The lower $K_{sat}$ for sod may be
attributed to thatch and fine particles that could not be removed during the sod washing
process. The seeded control was planted directly in the sand and synthetic matrix thus
avoiding any build up of organic and inorganic particles. One advantage of sand is reduced
compaction, however, Baker et al. (1988b) suggested that reinforcement materials could
spread the load associated with wear and reduce bulk density. Another possibility for
reduced system D_b could be related to the displacement of the heavier soil mineral by the lighter synthetic material. System D_b was also reduced effectively by solid tine aerification.

Soil moisture was considered the dominating factor on impact absorption when Rogers and Waddington (1989) evaluated silty clay loam athletic fields. In contrast, our study found that surface hardness was not correlated with soil moisture. Pearson correlation coefficients for the SportGrass control and seeded control were -0.12 and 0.16, respectively. Surface hardness ranged from 73.0 to 117.3 g and soil moisture ranged from 6.1% to 9.2%. The low water holding capacity of the sand combined with the stabilizing nature of the synthetic material may have been the most important factor in determining surface hardness in our study.

A wear by treatment interaction was only apparent on dry root mass below the synthetic backing. This interaction was due solely to the sodded treatment. The sod was infected with the root-invading pathogen, summer patch (*Magnaporthe poae*), and a sample must have been taken from the infected area after traffic when differences in turf quality were not noticeable. The synthetic matrix of SportGrass substantially reduced root weight when compared to the nonreinforced seeded control. This reduction, however, did not affect the above ground characteristics. Root development has also been shown by Adams and Gibbs (1989) to be reduced below the reinforcement material VHAF. One noticeable benefit was penetration through the backing material of SportGrass during solid tine aerification, as it allowed more roots to grow below the synthetic matrix.

With continued development of new reinforcement materials, further research is needed to determine if they provide a stable playing surface. Furthermore, research can justify the manufacturer claims and determine whether the products should be released to the
SportGrass was very effective in maintaining turf cover and turf quality, but provided a harder surface than nonreinforced controls. Also, SportGrass increased $K_{sat}$ and decreased system bulk density, however, it also reduced the amount of roots below 2 cm. SportGrass performed well under simulated traffic, but the performance when subjected to real traffic needs to be determined. The vegetative mat that occurs above the top of the SportGrass fibers may be beneficial to the SportGrass system. Vertical mowing to remove the mat above the SportGrass fibers increased surface hardness. This could compromise cleat penetration and reduce traction. A mat of vegetation and sand that extended approximately 12 to 19 mm above the SportGrass fibers provided better cushion and grip for cleated shoes.

REFERENCES


Table 1. Surface hardness for four treatments with SportGrass and two treatments without SportGrass measured with a 2.25-
kg hammer following traffic and recovery periods in 1998 and 1999. Higher $g_{\text{max}}$ values indicate a harder surface.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year 1 Before traffic</th>
<th>Year 1 After spring recovery</th>
<th>Year 1 After fall traffic</th>
<th>Year 1 After fall recovery</th>
<th>Year 2 After spring traffic</th>
<th>Year 2 After spring recovery</th>
<th>Year 2 After fall traffic</th>
<th>Year 2 After fall recovery</th>
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<td>With SportGrass</td>
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<td>Control</td>
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<td>Solid tine aerify</td>
<td>69.1</td>
<td>89.6</td>
<td>101.9</td>
<td>75.8</td>
<td>90.8</td>
<td>96.0</td>
<td>112.8</td>
<td>86.8</td>
</tr>
<tr>
<td>Plant growth regulator</td>
<td>70.7</td>
<td>92.1</td>
<td>107.8</td>
<td>85.0</td>
<td>104.2</td>
<td>104.6</td>
<td>116.5</td>
<td>90.4</td>
</tr>
<tr>
<td>Without SportGrass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeded</td>
<td>56.8</td>
<td>84.3</td>
<td>90.3</td>
<td>67.5</td>
<td>91.0</td>
<td>90.9</td>
<td>111.3</td>
<td>76.3</td>
</tr>
<tr>
<td>Sodded</td>
<td>52.0</td>
<td>72.8</td>
<td>75.5</td>
<td>64.4</td>
<td>80.8</td>
<td>87.7</td>
<td>108.1</td>
<td>71.3</td>
</tr>
<tr>
<td>LSD ($0.05$)†</td>
<td>3.8</td>
<td>3.5</td>
<td>3.3</td>
<td>10.5</td>
<td>5.5</td>
<td>4.1</td>
<td>NS</td>
<td>4.8</td>
</tr>
</tbody>
</table>

† LSD at $P \leq 0.05$ according to Fisher's least significant difference tests.
Table 2. Traction for four treatments with SportGrass and two treatments without SportGrass measured with a 45-kg cleated plate following traffic and recovery periods in 1998 and 1999. Traction was recorded as the amount of torque required to tear the surface.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year 1</th>
<th></th>
<th></th>
<th>Year 2</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>After</td>
<td>After</td>
<td>After</td>
<td>After</td>
<td>After</td>
</tr>
<tr>
<td></td>
<td>traffic</td>
<td>spring</td>
<td>fall</td>
<td>traffic</td>
<td>fall</td>
<td>spring</td>
<td>fall</td>
</tr>
<tr>
<td>With SportGrass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>66.5</td>
<td>66.3</td>
<td>58.2</td>
<td>87.7</td>
<td>72.8</td>
<td>64.2</td>
<td>57.5</td>
</tr>
<tr>
<td>Vertical mowing</td>
<td>71.0</td>
<td>71.0</td>
<td>61.8</td>
<td>93.7</td>
<td>62.5</td>
<td>57.0</td>
<td>56.3</td>
</tr>
<tr>
<td>Solid tine aerify</td>
<td>71.3</td>
<td>68.3</td>
<td>57.2</td>
<td>84.2</td>
<td>70.7</td>
<td>59.8</td>
<td>59.2</td>
</tr>
<tr>
<td>Plant growth regulator</td>
<td>70.5</td>
<td>70.0</td>
<td>62.3</td>
<td>85.3</td>
<td>66.8</td>
<td>66.8</td>
<td>61.2</td>
</tr>
<tr>
<td>Without SportGrass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeded</td>
<td>69.7</td>
<td>69.3</td>
<td>55.3</td>
<td>70.7</td>
<td>65.5</td>
<td>55.5</td>
<td>60.2</td>
</tr>
<tr>
<td>Sodded</td>
<td>68.0</td>
<td>67.8</td>
<td>59.6</td>
<td>61.2</td>
<td>62.2</td>
<td>55.0</td>
<td>57.8</td>
</tr>
<tr>
<td>LSD (0.05)†</td>
<td>NS</td>
<td>NS</td>
<td>3.8</td>
<td>5.1</td>
<td>5.1</td>
<td>5.0</td>
<td>NS</td>
</tr>
</tbody>
</table>

† LSD at \( P \leq 0.05 \) according to Fisher's least significant difference tests.
Table 3. Turf quality ratings for four treatments with SportGrass and two treatments without SportGrass following traffic and recovery periods in 1998 and 1999. Turf density, cover, and retention of vegetative mat or thatch was given more consideration when rating turf quality than turf texture or color.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year 1</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before traffic</td>
<td>After spring recovery</td>
</tr>
<tr>
<td>With SportGrass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical mowing</td>
<td>9.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Solid tine aerify</td>
<td>9.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Plant growth regulator</td>
<td>9.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Without SportGrass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeded</td>
<td>9.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Sodded</td>
<td>9.0</td>
<td>7.0</td>
</tr>
<tr>
<td>LSD (0.05)‡</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

† Ratings based on a 1 to 9 scale; 1 = worst; 9 = best; and 5 = minimally acceptable.

‡ LSD at $P \leq 0.05$ according to Fisher's least significant difference tests.
Table 4. Turf cover percentage for four treatments with SportGrass and two treatments without SportGrass following traffic and recovery periods in 1998 and 1999.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year 1 Before traffic</th>
<th>Year 1 After spring recovery</th>
<th>Year 1 After fall recovery</th>
<th>Year 2 After spring traffic</th>
<th>Year 2 After spring recovery</th>
<th>Year 2 After fall recovery</th>
<th>Year 2 After fall recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>With SportGrass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>99.0</td>
<td>99.0</td>
<td>91.3</td>
<td>94.7</td>
<td>86.7</td>
<td>91.7</td>
<td>76.7</td>
</tr>
<tr>
<td>Vertical mowing</td>
<td>99.0</td>
<td>99.0</td>
<td>94.7</td>
<td>96.3</td>
<td>91.7</td>
<td>96.3</td>
<td>80.0</td>
</tr>
<tr>
<td>Solid tine aerify</td>
<td>99.0</td>
<td>99.0</td>
<td>91.7</td>
<td>93.3</td>
<td>91.7</td>
<td>95.0</td>
<td>78.3</td>
</tr>
<tr>
<td>Plant growth regulator</td>
<td>99.0</td>
<td>99.0</td>
<td>94.7</td>
<td>96.3</td>
<td>93.3</td>
<td>96.3</td>
<td>81.7</td>
</tr>
<tr>
<td>Without SportGrass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeded</td>
<td>99.0</td>
<td>93.3</td>
<td>78.3</td>
<td>83.3</td>
<td>78.3</td>
<td>81.7</td>
<td>61.7</td>
</tr>
<tr>
<td>Sodded</td>
<td>99.0</td>
<td>91.7</td>
<td>73.3</td>
<td>75.0</td>
<td>70.0</td>
<td>75.0</td>
<td>51.7</td>
</tr>
<tr>
<td>LSD (0.05)†</td>
<td>NS</td>
<td>3.3</td>
<td>8.2</td>
<td>5.7</td>
<td>7.5</td>
<td>5.5</td>
<td>8.4</td>
</tr>
</tbody>
</table>

† Percentage of each plot covered by living turf.

‡ LSD at $P \leq 0.05$ according to Fisher's least significant difference tests.
Table 5. Surface hardness immediately before and after vertical mowing and solid tine aerification were performed. Higher $g_{\text{max}}$ values indicate a harder surface.

<table>
<thead>
<tr>
<th></th>
<th>Vertical mowing</th>
<th>Solid tine aerification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>75.7</td>
<td>83.9</td>
</tr>
<tr>
<td>After</td>
<td>94.3</td>
<td>96.8</td>
</tr>
<tr>
<td>LSD $(0.05)^{\dagger}$</td>
<td>9.1</td>
<td>8.1</td>
</tr>
</tbody>
</table>

$LSD$ at $P \leq 0.05$ according to Fisher's least significant difference tests.
Table 6. Dry root mass for four treatments with SportGrass and two treatments without SportGrass measured before and after simulated traffic was applied in fall 1999. Soil cores were divided into three zones: above the synthetic matrix (0 to 2 cm), within the synthetic matrix (2 to 5 cm), and below the synthetic matrix (5 to 17 cm).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Above synthetic matrix (0 to 2 cm)</th>
<th>Synthetic matrix (2 to 5 cm)</th>
<th>Below synthetic matrix (5 to 17 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Mean</td>
</tr>
<tr>
<td>With SportGrass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>10.66</td>
<td>10.60</td>
<td>10.63</td>
</tr>
<tr>
<td>Vertical mowing</td>
<td>9.40</td>
<td>9.49</td>
<td>9.44</td>
</tr>
<tr>
<td>Solid tine aerify</td>
<td>10.14</td>
<td>10.30</td>
<td>10.22</td>
</tr>
<tr>
<td>Plant growth regulator</td>
<td>10.90</td>
<td>10.25</td>
<td>10.57</td>
</tr>
<tr>
<td>Without SportGrass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeded</td>
<td>11.39</td>
<td>10.64</td>
<td>11.01</td>
</tr>
<tr>
<td>Sodded</td>
<td>7.58</td>
<td>7.48</td>
<td>7.53</td>
</tr>
<tr>
<td>LSD (0.05)†</td>
<td>1.74</td>
<td>1.20</td>
<td>1.85</td>
</tr>
</tbody>
</table>

†LSD at $P \leq 0.05$ according to Fisher's least significant difference tests.
Table 7. Saturated hydraulic conductivity ($K_{sat}$) and system bulk density ($D_b$) for four treatments with SportGrass and two treatments without SportGrass measured before and after simulated traffic was applied in fall 1999.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>$K_{sat}$ Before traffic</th>
<th>$K_{sat}$ After traffic</th>
<th>$K_{sat}$ Mean</th>
<th>$D_b$ Before traffic</th>
<th>$D_b$ After traffic</th>
<th>$D_b$ Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>With SportGrass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>30.6</td>
<td>26.1</td>
<td>28.4</td>
<td>1.55</td>
<td>1.56</td>
<td>1.56</td>
</tr>
<tr>
<td>Vertical mowing</td>
<td>28.8</td>
<td>21.3</td>
<td>25.1</td>
<td>1.55</td>
<td>1.56</td>
<td>1.55</td>
</tr>
<tr>
<td>Solid tine aerify</td>
<td>29.8</td>
<td>28.0</td>
<td>28.9</td>
<td>1.51</td>
<td>1.53</td>
<td>1.52</td>
</tr>
<tr>
<td>Plant growth regulator</td>
<td>30.8</td>
<td>26.2</td>
<td>28.5</td>
<td>1.56</td>
<td>1.56</td>
<td>1.56</td>
</tr>
<tr>
<td>Without SportGrass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeded</td>
<td>17.4</td>
<td>15.4</td>
<td>16.4</td>
<td>1.59</td>
<td>1.59</td>
<td>1.59</td>
</tr>
<tr>
<td>Sodded</td>
<td>9.6</td>
<td>8.3</td>
<td>8.9</td>
<td>1.60</td>
<td>1.60</td>
<td>1.60</td>
</tr>
<tr>
<td>LSD ($0.05$)</td>
<td>4.5</td>
<td>4.4</td>
<td>2.9</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

† System $D_b$ contained the synthetic portion of SportGrass system.

‡ LSD at $P \leq 0.05$ according to Fisher's least significant difference tests.
CHAPTER 4. GENERAL CONCLUSION

As athletic fields continue to utilize sand-based root zones, the use of reinforcement materials can help provide additional stability. This need for additional stability becomes especially beneficial during establishment of the field and the first season of activity. Products are being released on the market prior to any scientific research, however, and the claims made by the manufacturer often go untested. When subjected to simulated wear, the results of this study showed that SportGrass does provide some of the benefits stated by the manufacturer. SportGrass improved traction, turf cover, turf quality, saturated hydraulic conductivity, and bulk density. However, the use of SportGrass increased surface hardness and decreased the amount of roots that were able to grow within and below the synthetic matrix. An increase in surface hardness could be viewed as both beneficial and detrimental. Increasing hardness makes a field "stiffer", thus providing a firm surface that increases the potential for player speed. In contrast, a soft surface would produce a slower field. As a detriment, increasing hardness could reduce cleat penetration and compromise traction. The use of one cultural management technique, aerification, proved to be beneficial to the SportGrass system. The solid tines easily penetrated the backing and allowed the root system to grow through the backing. Also, it reduced surface hardness and bulk density. Aerification can be effectively used on a SportGrass system to manage surface hardness and improve rooting.
Future Research

This was the first extensive study on the SportGrass system, and the results showed there are some benefits to fields reinforced with SportGrass. Many questions, however, need to be answered about the long-term effects of SportGrass. Aerification and topdressing are practices used on sports fields. This process could possibly bury the SportGrass system and therefore alter the stability that it once provided. Long term studies on fields reinforced with SportGrass are needed. Our study applied simulated traffic, however, the protective vegetative mat was never completely removed. The SportGrass system needs to be evaluated under intense traffic that removes all green vegetation. The amount of recovery and rhizome production above and below the backing needs to be determined. Soil moisture had very little effect on the SportGrass system in our study. SportGrass needs to be evaluated during periods that simulate excessive rainfall. It appears to provide rapid water infiltration and provides reasonable footing even when conditions are saturated. Finally, while this study found that SportGrass increased surface hardness, more precise guidelines need to be established for surface hardness so that player safety is not compromised.
APPENDIX A. PARTICLE SIZE ANALYSIS

Particle size analysis for SportGrass root zone.

<table>
<thead>
<tr>
<th>Soil Separates</th>
<th>U.S. Standard Sieve</th>
<th>Diameter</th>
<th>Particle Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% no. mm % retained</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel</td>
<td>1.4%</td>
<td>10 2.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Very Coarse</td>
<td></td>
<td>18 1.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Coarse</td>
<td></td>
<td>35 0.5</td>
<td>19.4</td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>60 0.25</td>
<td>48.4</td>
</tr>
<tr>
<td>Fine</td>
<td>94.7%</td>
<td>100 0.15</td>
<td>18.6</td>
</tr>
<tr>
<td>Fine/Very Fine</td>
<td></td>
<td>140 0.10</td>
<td>2.9</td>
</tr>
<tr>
<td>Very Fine</td>
<td></td>
<td>270 0.05</td>
<td>0.9</td>
</tr>
<tr>
<td>Silt</td>
<td>2.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>1.9%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B. SOIL MOISTURE

Soil moisture for the SportGrass control and seeded control in Year 1 and Year 2.

Soil moisture and surface hardness correlation coefficients for SportGrass control and seeded control. Soil moisture was measured by the Gravimetry method. Surface hardness was measured in $g_{\text{max}}$ with a 2.25-kg hammer.

<table>
<thead>
<tr>
<th>Dates</th>
<th>Soil Moisture</th>
<th></th>
<th>%</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sportgrass Control</td>
<td>Seeded Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/4/98</td>
<td>6.8</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/25/98</td>
<td>7.0</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/29/98</td>
<td>8.4</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/6/99</td>
<td>8.6</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/14/99</td>
<td>6.2</td>
<td>6.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/25/99</td>
<td>6.8</td>
<td>9.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/7/99</td>
<td>6.1</td>
<td>8.2</td>
<td></td>
<td></td>
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<tr>
<td>5/13/00</td>
<td>6.2</td>
<td>7.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pearson correlation coefficient

-0.12     0.16
REFERENCES


Schmidt, W. 1982b. Comparative studies of Enkamat reinforcing mat on grass pitches. III. Results of investigations on mechanical aspects and soil physics. Z. Für Vegetationstechnik. 5:73-83.


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