ENHANCING PARTICIPANT SAFETY OF NATURAL TURFGRASS SURFACES INCLUDING AN INNOVATIVE NEW CONSTRUCTION SYSTEM FOR TURFED SPORT FIELDS

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Injuries on football fields and other sports surfaces can be grouped into different categories as related to the type of athletic movement and to the relative softness of the turf-soil surface. Many impact-type injuries are related to varying degrees of surface hardness, with the safety of the participant increasing inversely with a lessening of surface hardness. There are other surface playability characteristics of concern, such as traction, wear tolerance, divot opening/turf recovery, and smoothness. This paper will emphasize the aspect of hardness of natural surfaces.

Surface Hardness Assessment. The hardness and resultant safety of a surface can be measured using a light-weight portable apparatus, the Clegg Impact Soil Tester (5, 9). Several models of this device, with differing hammer weights of 1.5, 5.0 and 10.0 pounds, (0.5, 2.25, & 4.5 kg) are used in turf research. Each provides a relative scale of impact resistance (CIV) of the surface measured in gravities (g), with a decreasing CIV number indicating a lessening of hardness.

Comparisons of surface hardness for a variety of surfaces, from concrete to turfed soil, as assessed by the Clegg device with a hammer weight of 5 pounds, (2.25 kg), are shown in Table 1. Results indicate a decrease in surface hardness as the composition of the material becomes less dense (10). Major differences in hardness occur among solids, such as (a) high density cement, composition, or wood floor surfaces, (b) other types of artificial playing surfaces, and (c) the natural turf-soil surfaces. Turfgrasses at 100 gravities (g) and lower offer the least hard surface in comparison to other alternatives available for sports activities. This is due to the canopy biomass of the turf and the associated root zone that provide a uniquely resilient characteristic and cushion. Differences occur within the natural turf-soil surfaces with changes in (a) soil texture, (b) moist content, and (c) whether the surface is bare soil or turfed.

Table 1. Comparisons of the hardness of representative surfaces in the College Station, Texas area expressed as means of multiple observations of Clegg Impact Value (CIV).

Representative Surface Types	Clegg Impact Value - (g) with 5 lb. (2.25 kg) hammer
asphalt road	1442
cement floor	1426
composition running track	1432
tennis court - outdoor-composition	1422
basketball court - permanent wood	640
baseball - bare clay infield	504
football stadium - outdoor, 4-year old artificial surface	175
football stadium - indoor, 1-year old artificial surface	141
baseball - natural turfed field of bermudagrass	100

Turfgrass Effects. Sports participant safety on natural turfgrass is maximized through providing a dense biomass of above-ground turfgrass leaves, shoots, and stems grown on a stable, low-density root zone. Therefore, it is important to select the correct turfgrass species/cultivar, root zone, and cultural practices that have the capability of sustaining the highest possible biomass over the entire use period. Considerations should include the turfgrass species/cultivar adaptation, turfgrass wear stress tolerance, pest resistance, environment stress tolerance, and the ability to recover rapidly from turf injury during the time of year when intense use occurs. Proper turfgrass fertilization, irrigation, and cultivation practices also aid in maximizing the biomass cushion, thus lessening surface hardness. Results of several cultural studies as described in the following sections illustrate these effects.

Cutting Height Effects. Surface hardness of turfed sport venues can be modified by changing the height of cut. This was shown in a study with Tifway hybrid bermudagrass (*Cynodon dactylon* x *C. transvaalensis*) grown on a modified high-sand root zone at 7 heights of cut ranging from 0.5 to 10.0 inches (12-250 mm). Total shoot density was determined by counting the shoots per square dm.

As the height of cut increased the number of shoots per sq. dm decreased at each of the 7 heights (Table 2). The dry weight of the shoots per sq. dm decreased at each height up to 4 inches (100 mm) , then increased at 10 inches (250 mm). This was accompanied by a decrease in surface hardness from 0.5 to 1.0 inch (12 to 25 mm), then a stable readings to 2 inches (50 mm), and another plateau to 4 inches (100 mm), followed by a further decrease at 10 inches (250 mm). All results were within an acceptable hardness range. Although we assessed 7 heights of cut, the most appropriate turfgrass cutting height for football and other sports from the playability and turfgrass health standpoints should range from 0.5 to 2.0 inches. Turfed horse racing surfaces generally have higher cutting heights of 4 inches, especially for cool-season turfgrasses.

Table 2. Effects of 7 heights of cut on the surface hardness of a Tifway hybrid bermudagrass turf grown on a high-sand root zone.

Height of Cut inches (mm)	Clegg Impact Value - (g) with 5 lb. (2.25 kg) hammer
0.5 (12)	62 a*
1.0 (25)	58 bc
1.5 (37)	57 c
2.0 (50)	54 cd
2.5 (75)	51 d
4.0 (100)	51 d
10.0 (250)	47 e

*Means followed by the same letter within the same column are not significantly different at the 5% level, LSD t-test.

Nitrogen Fertility Effects. Small changes in surface hardness can be made by increasing the nitrogen fertility rate within the same height of cut (Table 3). The increased nitrogen fertility resulted in increased shoot biomass at each of 3 heights. However, in this study, the increasing height of cut effect on surface hardness was more dominate than the effect of an increased nitrogen nutritional level.

Table 3. Effects of 3 heights of cut and 3 nitrogen (N) fertilization levels on surface hardness expressed as 5-year means of the Clegg Impact Value (CIV) for Tifway hybrid bermudagrass grown on a modified high-sand root zone. 1989-1994.

Height of Cut inches (mm)	Nitrogen Rate Per Growing Month N lb/1,000 sq. ft. (N kg/100 m2)	Clegg Impact Value - (g) with 5 lb. (2.25) hammer
0.5 (12)	0.5 (0.25)	62 a*
0.5 (12)	1.0 (0.50)	58 ab
0.5 (12)	1.5 (0.75)	53 b
1.0 (25)	0.5 (0.25)	58 ab
1.0 (25)	1.0 (0.50)	53 b
1.0 (25)	1.5 (0.75)	60 ab
1.5 (37)	0.5 (0.25)	60 ab
1.5 (37)	1.0 (0.50)	59 ab
1.5 (37)	1.5 (0.75)	55 b

*Means followed by the same letter within the same column are not significantly different at the 5% level, LSD t-test.

Turfgrass Cultivar Effects. The effects of *Zoysia* cultivar selection and height of cut using the 1.1 pound (0.5 kg) hammer and the fourth drop indicate that surface hardness can be modified by cultivar selection and by height of cut. The softness benefits exceeded 50% among these 6 cultivars (Table 4). The increasing softness among cultivars was associated with an increase in shoot density and a higher leaf-to-stem ratio. The effects of an increased cutting height on enhanced softness of the surface were substantial as reported earlier.

Table 4. Effects of 6 mature Zoysia *cultivar turfs and 2 heights of cut on the surface hardness expressed as the Clegg Impact Value (CIV). Root zone is a modified high-sand.*

Zoysiagrass	**Height of Cut**		**Percent Change from 0.5 to 10.0 inch Cutting Heights**
	0.5 inch (12 mm)	**1.0 inch (25 mm)**	
Belair	69 a*	41 a	-41
El Toro	54 b	39 a	-28
Korean Common	55 b	35 a	-36
Meyer	48 bc	33 a	-31
FC 13251	44 c	31 ab	-30
Emerald	32 d	22 b	-31

*Means followed by the same letter within the same column are not significantly different at the 5% level, LSD t-test.

Root Zone Effects. Aside from turfgrass species/cultivar selection and culture, the other primary component that can be modified to decrease the hardness of natural turfgrass surfaces is via selection of the appropriate turfgrass root zone. Assessments shown in Table 5 indicate an increase in surface hardness occurred with changes in soil texture from high-sand to soils having more silt and clay. The range in CIV's for the 5 pound (2.25 kg) hammer weight on bare soils was 91 to 132 g and for turfed soils 88 to 116 g. There was 3 to 16% less hardness in turfed surfaces versus bare soil. The CIV's for the 3 loam soils were not within the acceptable hardness range. Soils with a high clay content develop, over time, a serious compaction problem that increases hardness, and results in a very unfavorable environment for root growth of turfgrasses.

Table 5. Comparisons of the hardness of 4 moist, non-turfed and turfed root zones.

Root Zone Texture	**Clegg Impact Value - (g) with 5 lb. (2.25 kg) hammer**		
	Soil only	**Soil and Turf**	**Percent Change**
high-sand mix (95% sand, 2% silt, 3% clay)	91	88	-3
sandy loam (86% sand, 6% silt, 8% clay)	102	97	-5
sandy clay loam (65% sand, 12% silt, 23% clay)	120	107	-13
clay loam (47% sand, 24% silt, 29% clay)	132	116	-16

*Means of 4 individual assessments per year over 3 years.

Mesh Inclusion Effects. The every increasing intensity of traffic on sports fields, and horse race tracks during the past three decades necessitated the development and use of high-sand root zones, such as the USGA Method for construction of root zones. This method minimized serious soil compaction problems and provided a higher quality, safer turfed playing surface. However, these root zones were relatively unstable under certain playing conditions.

In 1985, a series of long-term investigations were initiate at Texas A&M University to assess the use of randomly oriented, interlocking mesh elements for stabilization of high-sand root zones, while at the same time enhancing the environment for turfgrass root growth (1). These investigations were subsequently expanded in 1990 to include root zones with sandy clay loam and clay loam soil textures (11, 12).

The mesh elements, manufactured by Netlon Ltd., consist of discrete 2 x 4 inch (50 x 100 mm) rectangular units which have dimensional stability and flexural stiffness. Each element has open ribs extending from the perimeter and a square aperture between the mesh ribs of 0.4 x 0.4 inch (10 x 10 mm). The open ribs facilitate an interlocking structure that provides a unique three-dimensional matrix of a relatively fixed but microflexible nature. This three-dimensional, interlocking mesh element-root zone is distinctly different from the two-dimensional, non-interlocking, non-stabilized, fibrillated polypropylene fibers. The two-dimension types stabilize soils, but are deficient in the other beneficial turf aspects documented herein.

The mesh elements were combined with the soils in specific amounts of 4.2, 6.3, and 8.4 lb. per cubic yard (2.5, 3.75, and 5.0 kg per cubic meter) of soil, with rigorous mixing to ensure a completely random orientation of the mesh element pieces. The mesh-soil mix was then installed to a 6 inch (150 mm) depth over the same soil without mesh elements, which had been placed over a prepared subbase that included a drainage system. Three replicate plots of each mesh density rate and three plots of the same soil without mesh elements were then compared. In most of the studies, a topdressing with 1 inch (25 mm) of the same soil without mesh elements was placed over the mesh/soil matrix before planting the turfgrass, while one replication was not topdressed. This top layer proved to be of significant benefit, especially in reducing divot size and accelerating divot opening turf recovery.

Two traffic stress components were assessed over a 4-year period. The turf wear stress components were characterized by the divot opening length, width and depth, the rate of turf recovery in the divot openings, and the turf tear. The second traffic stress component, soil compaction, also was assessed via water infiltration rate, percolation rate, and surface hardness. Playing surface characteristics assessed were traction, ball bounce, surface hardness, and compression displacement. Soil moisture retention and turfgrass quality also were determined.

Results of the original field assessments were summarized in an earlier ASTM publication (2). Results of the subsequent field studies at Texas A&M University, which have been conducted for a minimum of 3 years for each soil texture, are remarkably similar, except for scale. Generally, as the volume of the interlocking mesh elements added to the root zone increased, there was a corresponding enhancement of the root zone/turfgrass complex, regardless of the soil texture, with the 8.4 lb. (5.0 kg) inclusion rate being best. There were relative scale differences between soils of different texture in some of the assessments. However, in all cases the addition of interlocking mesh elements was beneficial when compared to the same soil without mesh elements.

Surface hardness results shown in Table 6 indicate that with the 5 pound (2.25 kg) hammer, the range of CIV's for turfed soils with interlocking mesh elements was 69 to 87 g or 19 to 29% less hard than the same turfed soils without mesh. All of the soils containing interlocking mesh elements were within the acceptable playability range. The mesh imparted a dramatic improvement in relative softness of the surface which provides a cushion against potential injuries to sports participants.

Table 6. Effects of interlocking mesh elements on the hardness of 4 moist, turfed root zones.

Root Zone Textures	**Clegg Impact Value - (g) with 5 lb. (2.25 kg) hammer**		
	No-Mesh	**Mesh**	**Percent Change**
high-sand	88	69	-19
sandy loam	97	76	-19
sandy clay loam	107	84	-23
clay loam	116	87	-29

*Means of 4 individual assessments per year over 3 years.

Results of three other assessments affecting turf natural surface sport fields are included in this report: divot size; divot opening turf recovery; and water infiltration rate. The assessment apparatus used for these studies are described in the earlier referenced ASTM publications (2, 3). Divot size assessments for no-mesh and interlocking mesh element inclusions in 3 turfed soil textures are compared in Table 7. Divot opening lengths were decreased by the addition of interlocking mesh elements in all 3 soils, with the improvement ranging from 24 to 49%. Divot opening width also was improved by 14 to 22% as a result of interlocking mesh inclusion.

Table 7. Comparisons of divot opening length and width* for Tifway hybrid bermudagrass turf grown on 3 distinct root zones modified by 8.4 lb/cu. yd. (5.0 kg/m^3) of interlocking mesh element inclusions versus not mesh stabilized.*

Root Texture Zone	**Divot Opening Length (mm)**			**Divot Opening Width (mm)**		
	No-Mesh	**Mesh**	**% Change**	**No-Mesh**	**Mesh**	**% Change**
sand	134	102	-24	55	46	-16
sandy clay loam	141	95	-33	49	42	-14
clay loam	149	76	-49	54	42	-22

*Means of 4 individual assessments per year over 3 years.

The turf recovery of these divot openings for root zones with interlocking mesh inclusions was from 29 to 41% more rapid when expressed as days to 50% turf recovered, and 29 to 37% more rapid at the 75% turf recovery point (Table 8). The clay loam soil was the slowest in turf recovery, requiring 25 days and 30 days, respectively.

Table 8. Comparisons of divot opening turf recovery time for turfs grown on 3 distinct root zones modified with 8.4 lb cu. yd. (5.0 kg/m^3) of interlocking mesh element inclusions versus not modified.*

Root Zone Texture	**Divot Opening Turf Recovery**					
	Days to 50% Recovery			**Days to 75% Recovery**		
	No-Mesh	**Mesh**	**% Change**	**No-Mesh**	**Mesh**	**% Change**
sand	21	14	-33	8	20	-29
sandy clay loam	32	19	-41	41	26	-37
clay loam	35	25	-29	46	30	-35

*Means of 4 individual assessments per year over 3 years.

The water infiltration rates, assessed with a double-ring infiltrometer, were highest for the sand root zones and lowest for the clay loam root zones, but within each soil type an improvement was noted due to interlocking mesh element inclusion in the root zone (Table 9). The improvement varied from 47% for a sand to 93% for a clay loam root zone.

Table 9. Comparisons of water infiltration into 3 mature turf-root zones modified by 8.4 lb. per cu. yd (5.0 kg/m^3) interlocking mesh element inclusions versus not modified.

Root Zone Texture	**Infiltration Rate (mm per hour)**		
	No-Mesh	**Mesh**	**Percent Change**
sand	571*	1,069*	+47
sandy clay loam	<10	113	+91
clay loam	<5	75	+93

*Means of 4 individual assessments per year over 3 years.

Multidirectional Load-Bearing Capacity. An innovative testing apparatus was developed to approximate the rapid load applied by an athlete's shoe or horse's hoof to a turfgrass surface (6, 7). The test methods and simulation apparatus provide a means of quantitatively assessing root zone stability and improving root zone profile design to optimize the stability as well as agronomic performance for a wide range of turfgrass applications. Unlike earlier test methods, the apparatus applies a multi-dimensional, variable inclined, eccentric load to a footing. Replicated investigations of various root zone mixes and profile constructions were conducted and the deformability, mode of failure (divoting), and multi-directional bearing capacity compared for each. The investigation was extended to include testing of root zones with an established perennial ryegrass-Kentucky bluegrass (*Lolium perenne-Poa pratensis*) turf polystand.

The findings showed that root zone materials and profile constructions that have very similar bearing capacities when subject to vertical, centrally applied loading, i.e. the conventional Clegg impact test procedure, may exhibit very different performances under variable inclined, eccentric loading. The latter more nearly simulates the multi-directional loads imposed by an athlete's shoe or a horse's hoof. Inclusion of the three-dimensional, interlocking Netlon mesh elements increased the bearing capacity of all root zone mixes and favorably altered the mode of failure, without adversely increasing the surface stiffness. This increased strength without loss of resilience is of major significance to player and equestrian safety.

The rate of rotation of the footing offers a good indication of the tendency for a given turf surface to divot. Reductions in the rate of rotation due to increasing mesh element content and to turfgrass cover were characterized for the eccentric inclined load condition. The inclusion of mesh elements in the USGA Method construction improved the resistance to divoting by reducing the rate of rotation without a parallel increase in stiffness or surface resilience.

The principle findings from the research are as follows:

An innovative experimental system for applying rapid loading is developed for the testing of root zone materials and construction profiles for sports turf applications. It can apply a variety of vertical and inclined, eccentric rapid loads that better replicate the action of a horse's hoof or athlete's shoe, and can record the loads and settlements. Its rate of loading is sensitive to the surface stiffness.

The ultimate bearing capacity depends upon the magnitude, eccentricity and the relative direction of the initial load.

The incorporation of mesh elements was found to increase the ultimate bearing capacity and reduce the rate of rotation of the footing. This represents a reduction in the tendency for a sports turf to divot.

The increased load-bearing capacity provided by the mesh elements was not associated with an increase in surface stiffness. A significant benefit when considering player and equine safety.

The increase in ultimate bearing capacity of a USGA Method root zone under the inclined eccentric loading condition that was attributed to the turfgrass cover was 16%. When the root zone was reinforced with mesh elements, the combination of turfgrass cover and mesh elements increased the bearing capacity up to 108%.

Summary. These studies indicate that surface hardness can be decreased, with resultant increases in participant safety, through (a) selection of turfgrass species/cultivar, (b) height of cut, (c) nitrogen fertility regime, (d) root zone texture, and (e) use of 3-dimensional, interlocking mesh element inclusions. The 3-dimensional, interlocking matrix of the mesh plus the intertwining of grass roots within the mesh elements are a unique, one-of-a-kind system. It is the only soil stabilization system that has been extensively research for use in turfgrass-soil complexes. Based on the investigations describe herein and other long-term studies, the benefits from the addition of interlocking mesh elements to a turfed installation are:

enhanced soil stabilization, resulting in more secure footing.

less surface hardness, resulting in enhanced participant safety.

greatly improved load-bearing capacity, without an associated increase in hardness.

resistance to surface rutting from very heavy loaded wheels.

a 24 to 49 percent reduction in divot size.

a 29 to 41 percent faster divot opening turf recovery.

improved uniformity of ball bounce.

decreased soil compaction, that favors rooting of turfgrasses.

internal, microflexing for soil aeration that is needed for root growth.

increased water infiltration and percolation, for rapid removal of rain water.

improved soil moisture retention.

improved turfgrass rooting, overall turfgrass health and turf performance.

Although these benefits are realized within each soil type and each volume of interlocking mesh inclusion, the best overall root zone in these assessments was the high-sand root zone with a 8.4 pounds per cubic yard (5.0 kg per cubic meter) volume of interlocking mesh elements at an inclusion depth of 6 inches (150 mm). Also, it is essential to place a 1 inch (25 mm) non-mesh root zone on top to maximize divot reduction and turf performance on sport fields.

Potential uses for this interlocking mesh element/turfgrass root zone complex are numerous. Major installation types now in existence using the mesh are sports fields, golf course tees and cart paths, turfed horse race tracks, equestrian event arenas and show grounds, turfed roadways and parking areas, and heavy load-bearing areas such as fire truck access lanes.

In order to achieve this type of multi-functional surface that performs under a range of diverse stresses, it will be somewhat more expensive to install. However, it will function for a longer time and accommodate a much larger number of events, recreational activities, or traffic pressures which, in the long term, makes this system far more cost effective. Additionally, this system may provide the only answer to some unique, severe-stress turfgrass problems that had no other solution in the past.

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