

# Evaluating the Surface Performance of Four Shallow Profile Turfgrass Scenarios

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## Abstract

This case study evaluated four shallow profile turfgrass systems as distinct scenarios with respect to the Fédération Internationale de Football Association (FIFA) standards for football pitch performance. The systems consisted of sod on plastic (1.5-inch sand rootzone), over a nonwoven geotextile fabric and a modular subbase. Scenarios were defined as a rooted non-stabilized baseline (Reference), a non-stabilized turf simulating recent installation (Uprooted), a previously used rooted non-stabilized turf, and rooted turf reinforced with artificial fibers and backing (Stabilized). The objective was to determine whether systematic differences existed in volumetric water content (VWC), surface hardness, ball rebound, and rotational resistance across repeated weekly measurements. Treatment effects were detected for VWC, surface hardness, and ball rebound, whereas rotational resistance did not differ significantly. The Stabilized treatment maintained a lower VWC and greater surface hardness and ball rebound than the non-stabilized treatments. The Reference and Transplant treatments were generally similar, while the Uprooted displayed softer conditions and lower rebound. These findings indicate that shallow profile systems can differ in performance, but interpretation must account for additional systematic differences rather than attributing performance differences to a single factor. Future work should isolate reinforcement, rootzone composition, and rooting progression to determine the primary drivers of sustained playability in shallow profile turfgrass systems.

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## 1. Introduction

Turfgrass athletic fields are natural, regenerative surfaces expected to maintain safe and consistent performance across variable use and environmental conditions. Performance is often evaluated using field metrics that capture athlete-surface and ball-surface interactions, such as volumetric water content (VWC), surface hardness, ball rebound, and rotational resistance. VWC characterizes rootzone moisture status and is often associated with surface hardness and energy absorption (Caple et al., 2012; Dickson et al., 2018). Surface hardness represents impact response upon contact with a turfgrass

system, with values influenced by both rootzone properties and turf condition (Twomey et al., 2012). Ball rebound quantifies vertical energy return during ball-surface impact and has been closely associated with surface hardness (Baker and Gibbs, 1989). Rotational resistance quantifies the torque required to rotate a studded interface as a traction metric linked to athlete stability during directional change (Rogers et al., 1998).

Under conventional methodologies, turfgrass sports fields rely on a sand-based rootzone (minimum 8 in) over a drainage profile (ASTM F3339-20). Sand-based systems are used because they support rapid drainage

and are less prone to compaction than finer-textured soil mediums (Guisasola et al., 2010), providing consistent playing conditions under varying moisture content (Baker and Gibbs, 1989). While this conventional architecture is effective, it is generally associated with permanent construction and limited adaptability for rapid venue turnover.

Modern stadium operations increasingly require systems that can support multi-use schedules, including non-sporting events, short conversion windows, and repeated installation/removal cycles. In response, shallow profile systems have emerged using thinner sand layers over modular support/drainage elements rather than full-depth conventional architecture (James, 2011; Young et al., 2022). The shallow profile system utilizes sod grown on plastic, a propagation method in which turfgrass is seeded into a thin soil or sand medium placed over an impermeable barrier, such as a plastic. When the roots contact the physical barrier, growth continues laterally rather than downward, intertwining to form a contingent turfgrass stand that can be harvested in a shorter time frame than conventional propagation methods (Decker, 2002).

A variation of the shallow profile system is a stabilized carpet mat, in which natural turfgrass is grown into a reinforced backing and a synthetic fiber matrix that accounts for ~5% of the total turf coverage. Prior work on reinforced turfgrass systems indicates that the inclusion of synthetic materials can modify surface hardness, VWC, and traction responses (McNitt and Landschoot, 2003).

Within that context, this case study evaluated four shallow profile systems as distinct scenarios: a rooted reference, an uprooted/reinstalled disturbance, a previously used re-rooted transplant, and a stabilized carpet-mat system (Table 1). The objective was to evaluate systematic differences in performance across VWC, surface hardness, ball rebound, and rotational resistance.

## 2. Materials and Methods

### 2.1. Site Description and Experimental Design

The study was conducted at the Michigan State University (MSU) Hancock Turfgrass Research Center (HTRC) in East Lansing, Michigan. Data was collected weekly from October 20th to November 17th to evaluate the surface performance of four shallow profile turfgrass systems.

All treatments were established as sod on plastic over a 1.5-inch sand rootzone by Green Valley Turf Company (GVT) in Colorado, harvested from the plastic bilayer, and installed at the Hancock Turfgrass Research Center (HTRC) over a 6.0 mm nonwoven geotextile bilayer above an 85 mm modular sub-base system (Figure 1). The experiment was arranged as a randomized complete block design (RCBD), with three replications per treatment (12 total plots). Individual plots measured 2 ft x 3.5 ft. The treatments are defined in Table 1.

#### Figure 1. Shallow Profile Construction.

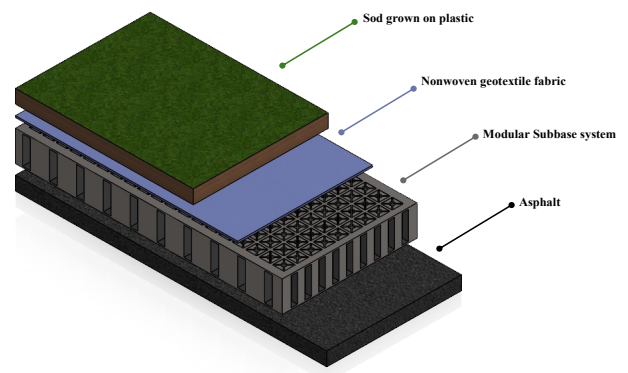


Figure 1. Original diagram prepared by Jacob M. Havican, Michigan State University, using SOLIDWORKS.

### 2.2. Management

To minimize nontreatment variability, all plots were managed uniformly throughout the study period, unless specified by the treatment description. Soil volumetric water content remained greater than 25% during the study period. No irrigation was administered due to rain events during the study period.

**Table 1. Treatment Definitions**

Treatment	Turf Species (seeded as)	Establishment Date	Age	Installation Timeline	Functional Definition
Reference	<i>Poa pratensis</i>	July 2023	~ 2.3 years	Installed July 2024 at the HTRC.	Baseline shallow profile system: turf remained rooted into the textile layer over the porous sub-base at testing.
Uprooted	<i>Poa pratensis</i>	July 2023	~ 2.3 years	Initially installed July 2024, then lifted and reinstalled 24 h before each measurement date.	Disturbance treatment; representing interface discontinuity between newly installed turf and textile layer above the porous subbase at testing.
Transplant	<i>Poa pratensis</i>	December 2022	~ 2.9 years	Initially installed June 2024 at AT&T Stadium returned to GVT, and reinstalled September 2024 at the HTRC.	Relocated, previously used sod, turf remained rooted into the textile layer over porous subbase at testing.
Stabilized	84% <i>Poa pratensis</i> , 16% <i>Lolium perenne</i>	April 2024	~ 1.6 years	Installed September 2024 at the HTRC.	Stabilized carpet-mat sod (5% polypropylene (PP) fiber matrix, 95% natural turfgrass and a PP backing); turf remained rooted into textile layer over porous subbase at testing.

Table 1. *Poa pratensis* = Kentucky bluegrass, *Lolium perenne* = Perennial ryegrass, HTRC= Hancock Turfgrass Research Center, GVT= Green Valley Turf Company, AT&T Stadium= Stadium in Dallas, Texas.

## 2.3. Laboratory Characterization

### 2.3.1. Organic Matter

Three soil cores (1.5 in diameter x 1.5 in depth) were collected from each plot, and composited to form one analytical sample per plot. Organic matter was determined by loss on ignition (LOI). Composite samples were placed in a crucible, oven-dried at 105° C to a constant mass (48 h), cooled to room temperature, and weighed to obtain dry mass. Dried samples were then combusted at 360° C for 6 hours, cooled to room temperature, and reweighed to obtain the post-combustion mass.

Organic matter (OM %) is calculated as:

#### Equation 1. Organic Matter %

$$OM\% = \left( \frac{W_{105} - W_{360}}{W_{105}} \right) \times 100$$

Where  $W_{105}$  is the oven-dried mass (g), and  $W_{360}$  is the post combustion mass.

### 2.3.2. Particle Size Analysis

For particle size distribution (PSD), three cores (1.5 in diameter x 1.5 in depth) were taken from each plot and combined to form one composite sample per plot. Composite samples were suspended in a hexametaphosphate solution to disperse particles and separate the inorganic and organic materials, and then dried prior to sieve analysis. PSD was determined by manual sieve analysis. Samples were separated through a nested U.S. standard sieve series: No. 10 (2.00 mm), No. 18 (1.00 mm), No. 35 (500  $\mu$ m), No. 60 (250  $\mu$ m), No. 100 (150  $\mu$ m), and No. 270 (53  $\mu$ m), with the pan representing materials less than 53  $\mu$ m. The sieve stack was hand-shaken for 5 minutes across samples. The mass retained on each sieve was recorded and assigned to a United States Golf Association (USGA) rootzone particle size class (USGA Green Section Staff, 2018): fine gravel (2.0-3.4 mm), very coarse sand (1-2 mm), coarse sand (0.5-1 mm), medium sand (0.25-0.5 mm), fine

sand (0.15-0.25 mm), very fine sand (0.05-0.15 mm), silt (0.002-0.05 mm), and clay. Plot-level fractions evaluated for compliance with USGA rootzone recommendations (USGA Green Section Staff, 2018) and ASTM (American Society for Testing and Materials) specifications for sports field rootzone mixes.

#### 2.4. Field Performance Measurements

Performance metrics were measured weekly at each plot across five sampling events (T0-T4): volumetric water content (VWC) %, surface hardness (gmax), ball rebound (cm), and rotational resistance (peak shear strength N · m).

VWC was measured using a Field Scout TDR 350 (Dennis Spectrum Technologies) with 1.5-inch tines, recording five subsamples per plot. Surface hardness was measured using a 2.25 kg Clegg Impact Soil Tester. The device consists of a suspended compaction hammer dropped from a fixed height. Upon impact, a connected accelerometer records the peak output corresponding to surface hardness (Clegg, 1976). The consistent procedure was followed, with three subsamples per plot. Ball Rebound was measured using an electromagnetic fixture to drop a Fédération Internationale de Football Association (FIFA) World Cup football from a fixed height. With rebound height calculated as:

#### Equation 2. Ball Rebound Height

$$\text{Ball rebound (cm)} = 1.23 \times (T - 0.025)^2 \times 100$$

Where T is the time interval between the first and second impacts following a 2 m drop.

Two readings were taken from each plot. Ball rebound was recorded at T0, T3, and T4. Before testing, the ball was inflated to 8.6 psi to achieve a predetermined rebound height of 1.3 m when dropped on asphalt.

Rotational resistance was measured using a Dennis Shear Strength tester, recording peak shear strength (N·m) applied by a studded disk (Canaway and Bell, 1986).

#### 2.5. Statistical Analysis

All analyses were conducted at  $\alpha = 0.05$  in R Studio. Repeated field metrics (VWC, surface hardness, ball rebound, rotational resistance) were analyzed using mixed-effects models. Pairwise mean separation for repeated metrics used Sidak-adjusted comparisons (Midway et al, 2020). Rootzone particle-size fractions and organic matter were analyzed using ANOVA with Tukey's HSD for mean separation (Midway et al, 2020). Means sharing a letter were not significantly different. Code is available from the author upon request.

### 3. Results

#### 3.1. System Characterization: Rootzone Particle Size and Organic Matter.

Rootzone composition differed among treatments before field performance testing. Particle size distribution showed treatment effects for the very coarse sand and medium sand. ( $p < 0.05$ ). Fine gravel, coarse sand, fine sand, very fine sand, and silt + clay fractions did not differ among treatments ( $p > 0.05$ ). The Stabilized treatment's rootzone contained less very coarse sand (7.2%) and more medium sand (41.1%) than the Reference, Uprooted, and Transplant treatments (11.6-11.9% very coarse sand; 33.2-36.3% medium sand) (Table 2). Fine gravel, coarse sand, fine sand, very fine sand, and the silt + clay fractions showed no significant differences among treatments. Despite differences in fraction sizes, all respective root zones met USGA recommendations and ASTM specifications.

The Stabilized Treatment displayed a significantly lower soil organic matter content (4.6%) than the Reference, Uprooted, and Transplant treatments (7.0-7.6%) (Table 3). Soil organic matter content did not differ among the Reference, Uprooted, or Transplant treatments.

#### 3.2. Volumetric Water Content

Treatment VWC declined from T0 to T3 and slightly increased from T3 to T4 (Figure 2). Week and treatment effects were significant ( $p < 0.05$ ). The treatment  $\times$

**Table 2. Treatment Rootzone Particle-size Distribution**

Treatment	F. Gravel	VCS	CS	Med	FS	VFS	<0.002 mm
%Retained							
Reference	0.23	11.9 a	35.4	34.2 b	9.7	5.9	2.7
Uprooted	0.20	11.8 a	35.0	33.2 b	9.8	5.7	4.3
Transplant	0.03	11.6 a	36.0	36.3 b	8.5	4.7	3.0
Stabilized	0.10	7.2 b	30.4	41.1 a	11.5	6.0	3.7
p value (<0.05)	NS	**	NS	**	NS	NS	NS
USGA rec.	≤ 3	≤ 10			≤ 20	≤ 5	≤ 8
ASTM spec.	≤ 20	≤ 20	25–50	> 25	< 10	< 5	< 8

Table 2. USGA recommends that coarse sand % + medium sand % are ≥ 60. F. Gravel=fine gravel, VCS= very coarse sand, CS= coarse sand, Med= medium sand, FS= Fine sand, VFS= very fine sand, <0.002 mm= silt + clay fractions. Means with the same letter were not statistically significant, (Tukey's HSD,  $\alpha = 0.05$ ). NS,  $p \geq 0.05$ , \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ . NS indicates no statistical significance.

week interaction was not significant, indicating that treatments followed a similar dry-down pattern during the measurement period. Across weeks, the Stabilized treatment maintained a lower VWC % (35.1 b) than Transplant (38.6 a) and Reference (39.0 a) (Table 5).

**Table 3. Treatment Soil Organic Matter Content**

Treatment	Organic matter %
Reference	7.0 a
Uprooted	7.6 a
Transplant	7.3 a
Stabilized	4.6 b
p value (<0.05)	***

Table 3. Means with the same letter were not statistically significant, (Tukey's HSD,  $\alpha = 0.05$ ). NS,  $p \geq 0.05$ , \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ .

### 3.3. Surface Hardness

Surface hardness differed among treatments and across measurement weeks, with no treatment x week interaction (Table 4). Across all sampling periods, the Stabilized treatment (70.8 a) displayed a harder surface than the

Reference (55.4 b), Transplant (51.8 bc), and Uprooted (48.8 c) treatments. The Stabilized treatment was the only treatment centered within the FIFA target band (70-85 gmax), whereas the non-stabilized treatments remained below that range across sampling dates (Figure 3).

### 3.4. Ball Rebound

Ball rebound differed by treatment and by week, while the treatment × week interaction was not significant (Table 4). Mean separation indicated that Stabilized had the highest ball rebound (80.1 a), Transplant (69.0 b), and Reference (67.6 b) did not differ significantly. The Uprooted treatment displayed the lowest ball rebound (58.4 c).

### 3.5. Rotational Resistance

Rotational resistance did not differ by treatment but did differ by week; the treatment × week interaction was not significant (Table 4). Treatment means were tightly grouped (19.3-19.8 N·m) (Table 5), indicating no evidence of treatment-level separation in rotational resistance across the study period.

**Figure 2. System Volumetric Water Content**

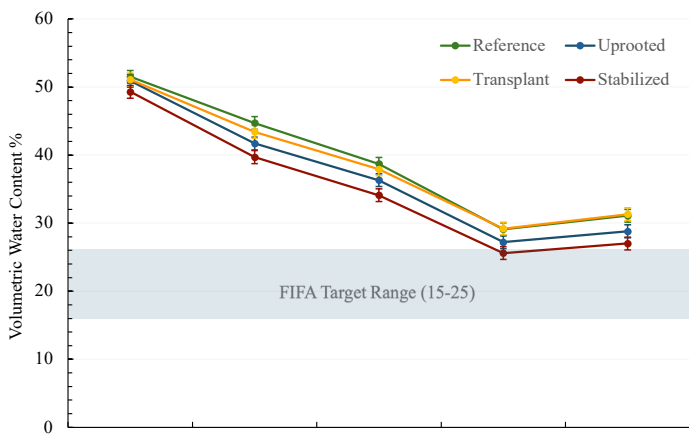


Figure 2. Estimated marginal means SE of volumetric water content %. The shaded band denotes target volumetric water content ranges specified by FIFA (15-25%).

**Figure 3. Surface Hardness Across Measurement Periods**

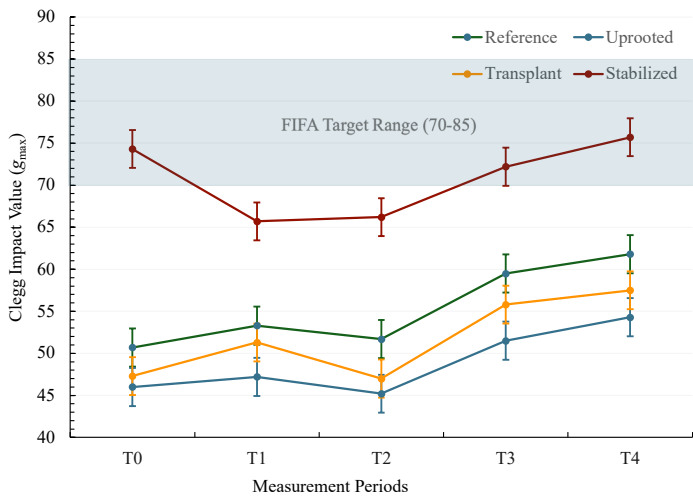


Figure 3. Estimated marginal means SE of surface hardness (gmax). The shaded band denotes target ranges specified by FIFA (70-85).

**4. Discussion**

The baseline characterization showed that the non-stabilized systems (Reference, Uprooted, and Transplant) were compositionally similar; in contrast, Stabilized treatment differed in species composition, organic matter, particle-size distribution, and reinforcement architecture. Accordingly, treatment differences involving the Stabilized treatment are interpreted as integrated system effects, rather

than as an independent reinforcement-only response.

**Figure 4. Ball Rebound by Treatment (pooled across T0, T3, and T4)**

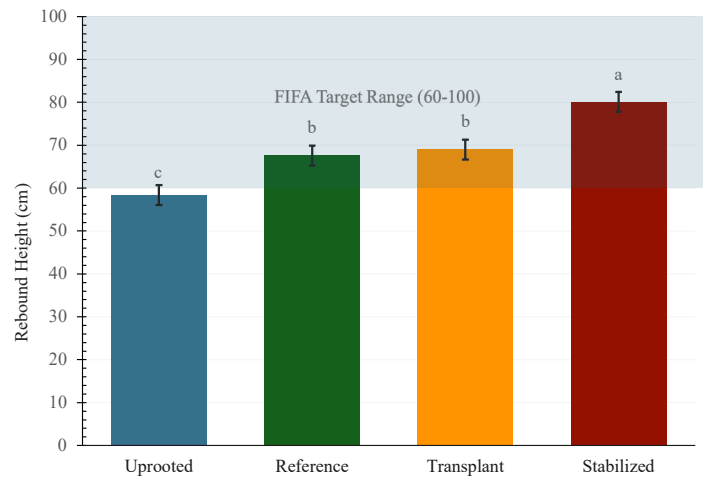


Figure 4. Estimated marginal means for ball rebound height (pooled across T0, T3, T4). Different letters indicate significant differences (Sidak-adjusted pairwise comparisons). The shaded band denotes ball target ranges specified by FIFA (60-100 cm).

Treatment effects were detected for VWC, surface hardness, and ball rebound, whereas rotational resistance did not differ among treatments. The lack of treatment separation for rotational resistance indicates that traction responses were more sensitive to week-to-week differences than vertical impact and moisture characteristics.

All treatments exceeded the FIFA target VWC range (15–25%; observed means: 35.1–39.0%). Only the Stabilized treatment met the FIFA hardness target (70–85 gmax), while the non-stabilized treatments remained below target (48.8–55.4 gmax).

Within the non-stabilized systems, Reference and Transplant performed similarly across measured playability metrics, suggesting that previously used sod can return to a comparable functional state after reinstallation and when rooting continuity is restored. In contrast, the Uprooted treatment produced a softer surface and lower ball rebound than the rooted non-stabilized treatments, consistent with the interface disruption created by repeated lifting and reinstallation.

The Stabilized treatment produced higher surface

**Table 4. Mixed model ANOVA summary for repeated field performance metrics**

	Volumetric Water Content (%)	Surface Hardness ( $g_{max}$ )	Ball Rebound (cm)	Rotational Resistance (N.m)
Treatment	9.558*	99.436*	30.826***	0.0509 NS
Week	654.739*	14.294*	36.734***	6.200*
Treatment x Week	0.614 NS	1.112 NS	1.643 NS	0.495 NS

Table 4. Values are F-ratios from repeated-measures mixed models. Fixed effects: treatment, week, and treatment  $\times$  week. Random effects: replication and subject (rep  $\times$  treatment). NS,  $p \geq 0.05$ ; \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ .

**Table 5. Treatment Means and Mean Separation for Repeated Performance Metrics**

Stabilized maintained the lowest VWC and highest surface hardness and ball rebound among treatments, while rotational resistance did not separate treatments.

	Volumetric Water Content %	Surface Hardness ( $g_{max}$ )	Ball Rebound (cm)*	Rotational Resistance (N · m)
Reference	39.0 a	55.4 b	67.6 b	19.8 a
Uprooted	37.0 ab	48.8 c	58.4 c	19.5 a
Transplant	38.6 a	51.8 bc	69.0 b	19.7 a
Stabilized	35.1 b	70.8 a	80.1 a	19.3 a

Table 5. Estimated marginal means for Volumetric Water Content %, Surface Hardness values ( $g_{max}$ ), Ball Rebound (cm), and Rotational Resistance (N · m) across collection dates. \*Ball Rebound recorded on T0, T3, T4. Different letters indicate significant differences (Sidak-adjusted pairwise comparisons). Means sharing a letter are not statistically significant at  $\alpha=0.05$ .

hardness, higher ball rebound than the non-stabilized treatments, and lower VWC. The literature on reinforcing inclusions has reported reduced soil water content and greater surface hardness relative to unamended systems (McNitt and Landschoot, 2003), findings that align with the lower VWC and higher  $g_{max}$  values observed for the Stabilized treatment. The accumulation of organic matter and thatch has been shown to reduce infiltration rates and alter water distribution in turf systems (Taylor and Blake, 1982), indicating that organic matter could plausibly contribute to the observed moisture separation. Unfortunately, the case study's design did not isolate individual factors; therefore, attributing performance outcomes to a single component would be inappropriate.

## 5. Conclusion

This case study demonstrated that shallow profile turfgrass systems can exhibit performance variability under the same environmental conditions and testing period. Overall, the evaluated systems did not meet FIFA moisture targets (VWC 35.1–39.0% vs. 15–25%), and only the Stabilized scenario met FIFA hardness standards (70.8  $g_{max}$ ). However, interpretations must be made with cognizance of differences in biological age, turfgrass species, rootzone composition, reinforcement architecture, and the aforementioned water content. The distinct characteristics of the Stabilized treatment indicate that further investigation into the effects of reinforced turfgrass is warranted using comparable treatments. The non-stabilized treatments appeared most comparable in

baseline composition and performance response. The Reference and Transplant treatments showed similar performance, suggesting the practical feasibility of sod reuse given adequate rooting upon reinstallation. In contrast, the Uprooted treatment consistently showed reduced surface firmness and rebound, indicating that interface disruption can measurably degrade performance. These findings support future work to define the rooting progression after installation and its relationship to sustained performance in shallow profile turfgrass systems.

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