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# The Effect of Soil Type and Moisture Content on Head Impacts on Natural Grass Athletic Fields †

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**Abstract:** Studies are warranted to evaluate head injury criterion (HIC) on athletic fields to determine baseline numbers and compare those findings to current critical thresholds for impact attenuation. A two year (2016 and 2017) study was conducted on University of Tennessee athletic fields (Knoxville, TN, USA) to determine the effect of soil type (cohesive soil, United States Golf Association sand specifications) and grass species (*Poa pratensis* and *Cynodon dactylon* × *C. transvaalensis*) on HIC. Additionally soil moisture conditions monitored were: dry (0.06–0.16 $m^3/m^3$), acceptable (0.17–0.29 $m^3/m^3$), and wet (0.30–0.40 $m^3/m^3$). A linear relationship ($r = 0.91$) was identified between drop height (0.5–2.9 M) and HIC value (35-1423 HIC) on granular root zones of both grass types. However, HIC on cohesive soil is a function of soil water content in addition to drop height. These results demonstrate to aid in head injury prevention on cohesive soil athletic fields the HIC can be lowered by managing soil water content.

**Keywords:** head injury criterion; soil water content; soil type; turfgrass

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## 1. Introduction

Nearly 38 million children and adolescents participate in organized sports, mostly on lower input municipal fields in the United States [1]. In 1999, it was estimated that in high school sports, 62,816 athletes suffer concussions annually [2]. A study completed in 2009 found that the number of concussions have risen to over 250,000 reported cases across all high school sports in the U.S. [3]. In college football, 5.5% of all players reported to have sustained a concussion during their playing career [4]. Approximately 10% of concussions are caused by an athlete's head impacting the playing surface [5]. Maintaining a safe playing surface is imperative in reducing the rate of sports related injury incidence.

Increases in athletic field surface hardness values can result in increased risk of concussions for athletes. Ground reaction forces, which are commonly 2.5 to 3.0 times greater than an individual's body weight during an athletic maneuver, have been cited as risk factors in the incidence of both chronic and acute athletic injuries [6,7]. As a surface becomes harder, the ground reaction forces increase on the athlete along with the potential for injury increases. Ground reaction forces are defined as the forces exerted on an athlete by the surface upon impact [8,9]. Poor playing quality on athletic fields can negatively impact player performance and safety [10]. Surface hardness and traction are key parts of the playing quality on an athletic field [11].

Current evaluations of natural grass athletic field surface hardness use the Clegg hammer. The Clegg utilizes a 2.25 kg hammer dropped from a height of 0.5 m; it is a flat bottomed missile in the shape of a cylinder with an accelerometer that reads in units of gravities [12]. While the Clegg gives surface hardness values, no correlation has been established between gravities and increased injury potential. However, the F355-E missile utilizes a hemispherical design that produces head injury criterion (HIC) values that have been associated with potential head injuries [13]. Head injury criterion were initially designed for automobile safety. The National Highway Traffic Safety Administration started using HIC as a standard based on the work of Gadd [14]. Today, HIC is used as the safety standard for head protection systems that use head forms [15]. Currently, the F355-E missile is used for testing the hardness of playground surfaces. In studies evaluating injuries, concussions occurred in most people at HIC levels of 250, while at HIC levels of 1000, 18% of people suffered traumatic brain injuries [13]. No research could be found using HIC to evaluate the hardness of athletic field surfaces or the use of the F355-E missile as an athletic field testing device. Further investigation is warranted to determine the effectiveness of the F355-E missile in finding differences in HIC values among root zone and grass species combinations.

Most athletic fields are constructed of soils native to the site or constructed sand. The inherently slow infiltration rates of native cohesive soils can be problematic when precipitation occurs prior to athletic events. Soils containing high amounts of silt and clay are impacted by soil water content (SWC) because of weak cohesive forces between water molecules and water acting as a lubricant decreasing solid-solid friction [16,17]. The amount of SWC in the soil is critical in managing the surface playing conditions of a native soil athletic field to provide safe and consistent playing surface. Most collegiate and professional American football fields are constructed following the USGA sand specification method. Sands are the primary component of high performance root zones because of its high particle stability, availability, and ability to maintain a point of maximum bulk density when compacted [18]. Unfortunately, the significant costs of construction of USGA specification root zones have prevented the widespread adoption of sand root zone constructions for all athletic fields [19]. In both root zones an inverse relationship between SWC and surface hardness has been identified [20,21].

The majority of athletic fields use either hybrid bermudagrass or Kentucky bluegrass depending on the region of the U.S. One study investigating athletic field traffic on Kentucky bluegrass and bermudagrass found significant differences in surface hardness values between species [22]. Investigating the potential differences in warm and cool season grasses HIC values is warranted. Therefore, the objective of this research was to determine to determine the effect of soil type (silt loam soil, United States Golf Association sand specifications) and grass species (*Poa pratensis* and *Cynodon dactylon* × *C. transvaalensis*) on HIC. Our hypothesis was higher HIC values would be found on cohesive root zones compared to sand root zones regardless of grass species.

## 2. Materials and Methods

A two year (2016 and 2017) study was conducted on University of Tennessee athletic fields (Knoxville, TN, USA) to determine the effect of soil type (cohesive soil, United States Golf Association (USGA) sand specifications) and grass species (*Poa pratensis* (KBG) and *Cynodon dactylon* × *C. transvaalensis* (bermudagrass)) on HIC. The cohesive soil was a Sequatchie silt loam soil (28% sand, 48% silt, and 24% clay) with a 6.2 soil pH, 9 mg $kg^{-1}$ initial phosphorous, 81 mg $kg^{-1}$ initial potassium, and 25 g $kg^{-1}$ organic matter content. The USGA sand root zone (0.7% very coarse, 14.3% coarse, 61.4% medium, 18.1% fine, 5.1% very fine, and 0.4% silt and clay by weight) was mixed with a 20% (volume) reed sedge peat moss [23].

Each root zone had three SWC ranges from wilting to field capacity, determined by the American Society for Testing Materials (ASTM) standard F1815-11 [24]. The cohesive root zone had a wilting point of (0.06 $m^3/m^3$) and field capacity (0.40 $m^3/m^3$), while the sand had a 0.05 $m^3/m^3$ wilting point and a 0.35 $m^3/m^3$ field capacity. Soil moisture conditions were: dry (just above wilting), acceptable (mid-point), and wet (field capacity). Overhead irrigation was applied or withheld to bring the soil root zone into the desired SWC range. Each experimental unit was watered to reach the desired range based on the average of seven SWC measurements (3.8 cm depth) collected using a handheld time domain reflectometer (TDR) probe (FieldScout 300 Probe, Spectrum Technologies, Inc. Plainfield, IL, USA).

Granular urea (46 N—0 $P_2O_5$–0 $K_2O$) was applied monthly at 49 kg N $ha^{-1}$, May through September, in both years of the study to bermudagrass plots. KBG plots were fertilized with granular urea (46 N—0 $P_2O_5$–0 $K_2O$) and was applied monthly at 25 kg N $ha^{-1}$ (March–May and September through November). Plots were mown at 2.2 cm (Bermudagrass) and 3.2 cm (KBG) plots three times per week using a triplex reel mower (TriKing 1900D; Jacobsen, Charlotte, NC, USA). Clippings were returned to the surface. Irrigation was applied as needed to prevent drought stress outside of testing conditions.

An F355-E testing device was used to quantify Head Injury Criterion (HIC). The HIC value is the time interval within the acceleration-time history of an impact over which the HIC integral is evaluated [25]. A 4.6 kg missile with a 16 cm diameter was attached to a tripod with electronic release for manual height adjustment. The HIC values were collected from 10 heights (0.5, 0.7, 1, 1.3, 1.6, 1.9, 2.2, 2.5, 2.7, and 2.9 m). Three drop were within a 15 to 20 cm area per drop height, under each SWC range. The HIC critical threshold of 1000 was established as the critical limit for this study corresponding with the ASTM standard [25]. The higher the drop height that 1000 HIC was reached, the safer the surface was for potential head injuries.

Analyses of covariance were conducted in SAS (v. 9.3; SAS Institute Inc., Cary, NC, USA). No significant year-by-treatment interactions were detected; therefore, data from each year were pooled. Soil water content was analyzed as a covariate. Fisher's least significant difference (LSD) was used to separate means at $\alpha = 0.05$. Non-linear, linear regressions, and correlations were conducted in SAS.

## 3. Results

Head impact criterion was affected by the interaction of grass species and soil type (Table 1).

**Table 1.** Analysis of covariance described the effects of year, grass species, soil type, and drop height on head injury criterion (HIC) in Knoxville, TN, USA in 2016 and 2017.

| Effect | DF | HIC |
|---|---|---|
| Grass [1] | 1 | NS [2] |
| Soil [3] | 2 | *** |
| Soil * Year | 2 | NS |
| Soil * Grass | 2 | * |
| Drop Height [4] | 5 | *** |
| Drop Height * Grass | 5 | NS |
| Drop Height * Soil | 10 | NS |
| Drop Height * Soil * Grass | 20 | NS |

[1] Two grass species (*Poa pratensis* and *Cynodon dactylon x C. transvaalensis*); [2] NS, not significant at the $p \leq 0.05$ level; [3] Two soil root zone (Sequatchie silt loam and USGA sand); [4] Drop heights investigated 0.5, 0.7, 1, 1.3, 1.6, 1.9, 2.2, 2.5, 2.7, and 2.9 m; * Significant at the 0.05 probability level; *** Significant at the 0.001 probability level.

Kentucky bluegrass on cohesive soils reached the ASTM playground standard ≤1000 HIC at the lowest height (1.9 m) compared with other grass by soil combinations (Figure 1). Bermudagrass on cohesive soils reached the 1000 HIC at 0.3 m higher than KBG on the same root zone. Bermudagrass and KBG HIC values were not significantly different on the USGA sand root zones (Figure 1).

Both grasses on the sand root zone reached the critical threshold of 1000 HIC at the highest drop height of all combinations tested. Soil water content affected HIC of cohesive soils while sand root zones were not impacted (data not shown). A linear relationship (r = 0.91) was identified between drop height and HIC value on granular root zones of both grass species. However, HIC on cohesive soil was a function of SWC and drop height.

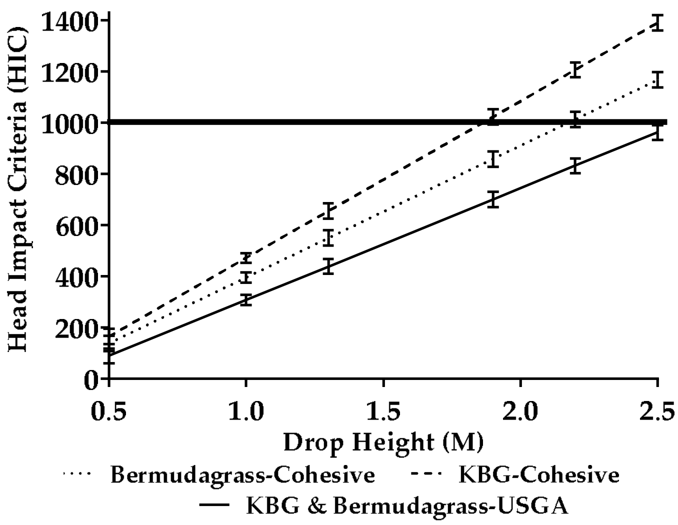


**Figure 1.** Head injury criterion response to changes in drop height on grass species (*Poa pratensis* (KGB) and *Cynodon dactylon* × *C. transvaalensis* (bermudagrass)) and root zone (Sequatchie silt loam (Cohesive) and United States Golf Association sand specification (USGA)) in 2016 and 2017. Error bars represent Fisher's LSD values at $\alpha \leq 0.05$ as a means of statistical comparison. Black line in graph represents the critical threshold when ≤1000 HIC.

## 4. Discussion

Due to the hardness of the surface potentially impacting HIC values, SWC was collected to be used as a covariate. Previous research has established that surface hardness has an inverse relationship with SWC on cohesive root zones [20,25]. Assuming a similar relationship existed with HIC and SWC, the authors collected a wide range of values to control the influence of SWC on this study. Cohesive soils SWC influenced HIC values, while sand root zones were unaffected. A similar inverse relationship was established between HIC and SWC on cohesive root zones. Cohesive root zones are affected because of weak cohesive forces between water molecules and water acting as a lubricant decreasing solid-solid friction decreasing the hardness of the surface under high SWCs [16,17]. The benefit of water impacting cohesive root zones is that increasing the SWC lowers the HIC. Sand root zones were not impacted due to the stability of the particle selection and low silt plus clay content.

Cohesive root zones of either grass species exhibited a linear relationship between drop height and HIC value when corrected for SWC. The linear relationship in cohesive soil was expected due to the increased height of the head form falling a greater distance, which equated to greater force being applied to the surface. The cohesive root zones had higher silt plus clay content, in turn making the surface firmer in the absence of water than the sand root zones. The firmer surface of the cohesive root zones resulted in lower critical HIC values in this study. The greater amount of vegetative material of bermudagrass compared with KBG could be attributed with the higher critical HIC. One limitation of this study was that no traffic was applied and potential differences could develop as grass becomes warn and compaction increases.

Sand root zones exhibited the highest critical HIC values regardless of grass species. These results suggest that sand root zones have a greater impact on HIC than amount of vegetative cover. Both grass species had the same sand root zone mix with less than 5% silt plus clay, allowing for a softer surface. One study found that increases in silt plus clay content over 12% increased soil bearing capacity compared with 5% or less [26]. The decrease in soil bearing capacity compared with the cohesive soil allows for greater absorption of the missile into the surface. The hypothesis was confirmed that cohesive soils have a higher critical HIC value regardless of grass species. Also, Henderson et al. [26] showed that as silt plus clay increased porosity decreased, the higher porosity explains why SWC did not impact sand root zone critical thresholds.

Further Investigation into differences between how low and high HIC values correlate with potential lower extremity injuries is important. Previous research has indicated that low surface hardness values corresponded to a greater soft tissue injury in athletes when measured with the Clegg [27]. While a soft surface may be ideal for reduced concussions, it may increase soft tissue injury potential. Future work needs to identify where HIC values reduce the potential for both head and soft tissue injuries. Due to increased use of synthetic athletic fields a HIC comparison between natural and synthetic surfaces is warranted. Determining the impact of synthetic turf surfaces under a variety of constructions (infill depths, shock pads, fiber length, etc.) could influence HIC values. While this study provides a start for HIC use on natural grass athletic fields, more work is still needed.

## 5. Conclusions

The use of HIC on athletic field surfaces provides a more accurate measurement of the head injury potential than traditional techniques. This study demonstrates that the F355-E missile can detect differences in surface values and was identified as a tool to monitor potential head injuries on athletic fields. Cohesive soil athletic fields can control HIC values by managing SWC. Grass species has minimal impact of the critical HIC threshold, while soil type made a significant difference. The USGA sand root zones provide the optimum root zone for reduced HIC values regardless of grass species.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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