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Surface Conditions of Highly Maintained Baseball Fields in the Northeastern United States: Part 1, Non-Turfed Basepaths

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Abstract

Quantitative information about the playing surface quality of highly maintained non-turfed basepaths is minimal. Playing surface quality has many components including surface hardness and pace. Hardness is the degree to which forces are attenuated upon impact with a surface. Pace is a measure of the relative velocity at which a ball travels after impacting a surface. A survey was conducted in 2005 to document the hardness and pace of non-turfed baseball field basepaths in the northeastern United States. Non-turfed basepaths measured very high in surface hardness, often exceeding maximum safety levels set by the United States Consumer Product Safety Commission. Other basepath characteristics such as soil texture, soil moisture, concentration of calcined clay conditioner, and scarification depth were documented and compared to surface hardness and pace.

Introduction

The playing quality of surfaces used for soccer has been thoroughly documented (5,7,8,9). The effect varying turfgrass characteristics have on surface hardness has been investigated (13,19,28), as has the pace of balls striking the surfaces of cricket and soccer fields (1,6,9). However, little information has been published on the surface hardness or pace of the non-turfed basepath portion of baseball fields.

Pace is a measure of the relative velocity at which a ball travels after impacting a surface compared to its velocity prior to impact. Although baseball is a sport where ball-to-surface interactions are common, the pace of baseball field playing surfaces has not typically been measured directly. Rather, it has been inferred through measurements of vertical ball rebound and ball-to-surface friction (18). Surfaces with excessive pace may affect player safety. The US Consumer Product Safety Commission reported that 77% of all youth baseball injuries are the result of being struck by the ball (23). While a player is often hit with a baseball without the ball first striking the surface, excessive surface pace may be a factor. Additionally, if researchers are to conduct studies concerning the non-turfed portion of baseball fields, documentation of the condition of existing baseball field playing surfaces would be useful.

Surface hardness is a key factor in playing surface safety and has been shown to not only affect players when they fall on the surface, but also affect the incidence of chronic and acute lower extremity injuries such as delayed onset muscle soreness and anterior cruciate ligament (ACL) rupture (10,14,15,21,24,25).

Surface hardness should be related to playing surface pace (6,9,29). Theoretically, harder playing surfaces attenuate less of the forces generated during ball-to-surface impacts; thus, balls move at higher velocities after impact with harder surfaces compared to softer surfaces.

Various factors may affect surface hardness and pace. On baseball fields, the non-turfed basepath soils are often highly compacted during construction (27).

In order to provide a more favorable surface for competition, field managers loosen the uppermost portion of these soils with scarifying equipment. A porous ceramic amendment, calcined clay, is often applied to the loosened portion of the soil (as a topdressing) to create a uniform color, keep the surface loose when players slide, and to manage soil moisture content (27). All of these factors (soil texture, bulk density, soil moisture, depth of scarified soil, and amount of calcined clay) may affect surface hardness and pace.

The objective of this research was to document the surface hardness and pace of the non-turfed basepaths of highly maintained baseball fields in the northeastern United Sates and to document some surface characteristics that may or may not affect surface hardness and pace.

Field Sampling Scheme

In the summer of 2005 a survey of baseball fields was conducted across the northeastern United States. The survey included three Major League Baseball fields (MLB), five minor league baseball fields (Professional), six National Collegiate Athletic Association fields (NCAA), and one municipal field (Other). These fields were distributed across the following states: Illinois, Maryland, Massachusetts, Minnesota, Ohio, Pennsylvania, and New Jersey. Three 6.1-m by 6.1-m sampling zones were chosen on the non-turfed basepaths of each field. One sampling zone was located between first and second base and a second zone was between second and third base. The middle of these two zones were 6.5 m from first and third bases, respectively. A third sampling zone was centered upon second base.

All fields were "in use" during the testing period. Measurements were made on days when the fields did not have a scheduled game. Field managers were not asked to do anything to prepare the basepaths for testing outside of their normal maintenance routine.

Playing Surface Hardness and Pace Measurements

A Clegg Impact Soil Tester (CIST) (2,16), equipped with a 2.25-kg missile, was used to measure the impact attenuation of each zone, which was reported as Gmax (2,19). The average of six CIST measurements in different locations was used to represent the surface hardness of each sampling zone.

Surface pace was quantified in each sampling zone by measuring the coefficient of restitution (COR) of a baseball impacting the surface. COR is defined as the ratio of two velocities; the velocity of a ball after impact with the surface divided by the velocity of the ball prior to impact (12). An apparatus termed Pennbounce was used to measure COR (Fig. 1). The apparatus uses a CO_2 powered air-cannon ('Storm 300,' Air Cannon Inc., Denver, CO) to propel baseballs at varying velocities and impact angles. The apparatus contains two pairs of infrared ballistic screens that are equipped with chronographs (Oehler Research, Austin, TX) to measure the velocity of the ball before and after impact with the playing surface (12). A more thorough description of this apparatus has been published by Brosnan et al. (12). In this experiment all measurements were made using Pennbounce configured at a 0.44-radian impact angle (25°) and a testing velocity of 40.2 m/sec (90 mph), as previous research found this configuration to best represent ball-to-surface interactions on baseball field playing surfaces (12). The average of six measurements in different locations was used to represent the surface pace of each sampling zone.

Fig. 1. Pennbounce apparatus for measuring playing surface pace (COR).

Surface Characterization

The depth of scarified soil was measured in each sampling zone using a point gauge. The gauge consisted of a pointed metallic rod attached to a ruler. The rod was inserted into the scarified soil surface until contacting the underlying soil sub-base. The depth of penetration was recorded. The average of six sub-samples was used to represent the depth of scarified soil within a sampling zone.

Two soil samples were removed from the loosened portion of each sampling zone. The loose volume of each soil sample was estimated using a graduated cylinder (11). The samples were weighed after drying to a constant weight at 105° C and loose soil bulk density values were calculated. A rough estimate of the percentage of calcined clay in each sample was then calculated using the equation, Calcined Clay (%) = 315.43 – 247.52 × Loose Bulk Density. Brosnan and McNitt (11) found this equation to be significant at the $P \leq 0.001$ level with an R^2 value of 0.97 using a single soil. This equation provides only a rough estimate of the amount of calcined clay in these soils, as most of the non-turfed basepaths in this study had a similar textural analysis to the soil used by Brosnan and McNitt (11). For a more precise estimation a new scale should be created for each soil.

Textural analysis and sand fractions were also determined for each sample (ASTM F-1632) (4).

Statistical Analysis

The experimental design was completely randomized. Means were calculated for each sampling zone within each field, and each sampling zone across all fields. Means were analyzed using the GLM procedure in SAS STAT software (version 9.1, SAS Institute Inc., Cary, NC). Means separation was performed when the F-ratio was significant at the 0.05 level. Means were compared using a Duncan's new multiple range test ($\alpha = 0.05$). Pearson's correlation coefficients were calculated to determine relationships between measured variables.

Surface Hardness Measurements

Across all fields tested, surface hardness averaged 171.0 Gmax with a range of 241.5 to 92.7 (Table 1). Surface hardness values also varied by sampling zone, with the third base zone measuring slightly lower than the first and second base zones (Table 2). Reduced foot traffic at third base (20) may have minimized the degree of soil compaction resulting in lower surface hardness (Gmax) values.

Table 1. Mean surface pace, surface hardness, soil moisture content, depth of scarified soil, and calcined clay content values for non-turfed basepath surfaces evaluated in a survey of baseball fields in 2005.

Field	**Surface pace**[x] (COR)	**Surface hardness**[y] (Gmax)	**Soil moisture content** (m^3/m^3)	**Depth of scarified soil** (mm)	**Calcined clay content** (m^3/m^3)
MLB 1	0.526 bc	92.7 h	0.299 a	25.1 a	92.6 a
MLB 2	0.514 c	114.8 g	0.283 a	11.9 b	100.0 a
MLB 3	0.566 a	177.5 e	0.231 b	8.2 cde	27.5 b
Prof. 1	0.584 a	215.3 b	0.160 de	5.4 gh	0.0 c
Prof. 2	0.576 a	132.8 f	0.242 b	6.6 efgh	20.9 b
Prof. 3	0.575 a	241.5 a	0.051 g	5.8 fgh	7.0 c
Prof. 4	0.575 a	203.6 bcd	0.087 f	6.6 defgh	0.0 c
Prof. 5	0.548 ab[z]	134.3 f	0.095 f	8.7 cd	24.0 b
NCAA 1	0.557 ab	196.4 cd	0.169 d	7.7 cdef	0.0 c
NCAA 2	0.570 a	193.8 cd	0.161 de	7.4 cdefg	3.8 c
NCAA 3	0.573 a	205.3 bc	0.084 f	4.8 h	30.7 b
NCAA 4	0.575 a	215.4 b	0.144 e	6.9 defg	28.6 b
NCAA 5	0.581 a	189.6 de	0.046 g	8.3 cde	0.0 c
NCAA 6	0.549 ab	106.0 gh	0.198 c	11.9 b	0.0 c
Other	0.566 a	145.5 f	0.228 b	9.1 c	39.1 b
Overall mean	0.562	171.0	0.165	8.9	26.8

[x] Surface pace (COR) = the ratio of the velocity of a ball after impact with a surface divided by the velocity of a ball prior to impact.

[y] Surface Hardness (Gmax) measured with the Clegg Impact Soil Tester using a 2.25 kg missile.

[z] Means with different letters are significantly different from one another (Duncan's nMRT, $\alpha = 0.05$).

Table 2. Average surface pace, surface hardness, soil moisture content, and depth of scarified soil values measured for each sampling zone across all fields evaluated in a survey of baseball fields in 2005.

Base	**Surface pace**[x] (COR)	**Surface hardness**[y] (Gmax)	**Soil moisture content** (m^3/m^3)	**Depth of scarified soil** (mm)	**Calcined clay content** (m^3/m^3)
First base	0.568 a[z]	179.6 a	0.165 a	9.5 a	32.0 a
Second base	0.553 b	171.9 b	0.164 a	8.3 b	22.8 a
Third base	0.567 a	161.4 c	0.166 a	9.1 ab	25.5 a

[x] Surface pace (COR) = the ratio of the velocity of a ball after impact with a surface divided by the velocity of a ball prior to impact.

[y] Surface Hardness (Gmax) measured with the Clegg Impact Soil Tester using a 2.25 kg missile.

[z] Means with different letters are significantly different from one another (Duncan's nMRT, $\alpha = 0.05$).

Surface Pace Measurements

Surface pace (COR) measurements averaged 0.562; thus indicating that the velocity of a baseball will be reduced by approximately 44% upon striking a non-turfed basepath surface at a 0.44-radian (25°) impact angle (Table 1). Surface pace measurements varied by only 7%, with a range of 0.581 to 0.514 (Table 1). This consistency indicates the ability of these baseball field managers to create consistent playing conditions.

Characterization of Basepath Soils

The basepath soils contained an average of 8.0% gravel, 66.6% sand, 18.1% silt, 7.3% clay (Table 3). The percentages of gravel and sand listed in Table 3 include calcined clay which has an average particle size diameter of 1.18 mm ('Turface MVP,' Profile Products, Buffalo Grove, IL).

Table 3. Soil texture, sand size, coarse-to-fines ratio, and calcined clay content values for non-turfed basepath soils evaluated* in a survey of baseball fields in 2005.

Field	Gravel	Sand	Silt	Clay	**Sand fractions** (mm) >2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.15	0.15-0.05	Coarse-to-fines ratio (> : < 0.05 mm)	Calcined clay content (m^3/m^3)
	(percentage)											
MLB 1	2.4	67.4	19.4	10.7	2.4	26.0	18.9	9.5	4.5	8.5	2.3 : 1	92.6
MLB 2	6.3	72.0	18.4	3.2	6.3	43.8	13.5	5.9	3.8	5.0	3.6 : 1	100.0
MLB 3	5.5	72.6	12.3	9.6	5.5	13.8	10.2	15.2	18.9	14.4	3.6 : 1	27.5
Prof. 1	3.5	60.2	29.4	7.0	3.4	14.6	11.0	9.0	6.9	18.8	1.7 : 1	0.0
Prof. 2	7.7	70.7	21.0	0.6	7.7	24.1	15.9	10.4	6.8	13.5	3.6 : 1	20.9
Prof. 3	1.5	65.8	28.2	4.5	1.5	10.2	10.1	22.4	11.6	11.5	2.1 : 1	7.0
Prof. 4	4.6	53.7	30.8	10.7	4.6	12.9	8.4	6.5	6.1	19.8	1.4 : 1	0.0
Prof. 5	13.2	76.3	9.6	0.9	13.2	26.9	23.7	15.4	7.6	2.7	8.5 : 1	24.0
NCAA 1	16.1	68.5	7.3	8.1	16.1	13.3	17.3	22.0	9.2	6.8	5.5 : 1	0.0
NCAA 2	8.9	64.6	18.7	7.7	8.9	10.1	8.7	23.3	11.4	11.1	2.8 : 1	3.8
NCAA 3	13.1	59.7	14.0	13.2	13.1	14.8	14.8	18.3	6.7	5.1	2.7 : 1	30.7
NCAA 4	5.9	56.2	24.2	13.7	5.9	15.0	13.5	14.9	6.7	6.0	1.6 : 1	28.6
NCAA 5	3.1	71.7	16.0	9.2	3.1	12.4	19.0	25.5	8.9	5.9	3.0 : 1	0.0
NCAA 6	15.7	69.7	11.2	3.7	15.7	20.4	17.0	13.3	8.1	10.9	5.8 : 1	0.0
Other	11.9	69.3	11.6	7.1	11.9	35.3	17.4	8.0	3.7	4.9	4.3 : 1	39.1
Overall Mean	8.0	66.6	18.1	7.3	8.0	19.6	14.7	14.6	8.1	9.7	2.9 : 1	26.8

* Soil samples collected from loosened soil surface. Gravel and sand fractions include calcined clay particles (average particle size diameter 1.18 mm).

Non-turfed basepath soils averaged a 3:1 ratio of coarse (> 0.05 mm) to fine (< 0.05 mm) particles (Table 3). All but three mixes (Professional #5, NCAA#6, NCAA#1) were within two standard deviations (± 1.74:1) of the mean. Variation in surface hardness and pace may be a result of differences in how these surfaces were installed and maintained rather than differences in material properties. For example, mixes varied considerably in estimated calcined clay content (± 30.9%), which was significantly correlated to both hardness and pace (Table 4)

Table 4. Correlation coefficients (n = 45) between surface pace (COR), surface hardness, calcined clay content, soil moisture content, scarfied soil depth, and coarse-to-fines (% > 0.05 mm : % < 0.05 mm) ratio means measured during a survey of baseball fields in 2005.

Parameter	**Surface pace** (COR)[x]	**Surface hardness**[y]	**Soil moisture content**	**Depth of scarified soil**
Surface pace (COR)	—	0.513***	-0.389**	-0.467**
Surface hardness	0.513***	—	-0.684***	-0.681***
Soil moisture content	-0.389**	-0.684***	—	0.574***
Depth of loose soil	-0.467**	-0.681***	0.574***	—
% Calcined clay	-0.489***	-0.522***	0.611***	0.599***
Coarse to fines ratio	-0.239	-0.520**	0.248	0.152

[x] Surface pace (COR) = the ratio of the velocity of a ball after impact with a surface divided by the velocity of a ball prior to impact.

[y] Surface Hardness (Gmax) measured with the Clegg Impact Soil Tester using a 2.25 kg missile.

*, **, *** Significant at the $P \leq 0.05$, 0.01, and 0.001 level, respectively.

Differences in soil moisture content and the depth of scarified soil on the surface were observed among non-turfed basepath surfaces. Soil moisture content values ranged from 0.299 to 0.046 m^3/m^3, with a mean of 0.165 m^3/m^3 (Table 1). The depth of scarified soil ranged from 25.1 to 4.8 mm, with a mean of 8.9 mm (Table 1).

Correlations

Low but significant correlations were detected among properties measured (Table 4). COR values were significantly correlated with soil moisture content ($r = -0.389$, $P \leq 0.01$), the depth of scarified soil on the surface ($r = -0.467$, $P \leq 0.001$), and the amount of calcined clay on the surface ($r = -0.489$, $P \leq 0.001$). The same parameters were also significantly correlated to surface hardness. COR and surface hardness were significantly correlated to one another as well ($r = 0.513$, $P \leq 0.001$).

These relationships imply that surface pace was greater on harder, drier surfaces. Increasing the depth of scarified soil on the surface was significantly associated with a decrease in surface pace. Increasing scarification depth on a bare soil surface has been reported to reduce surface hardness on thoroughbred racetracks (26). The depth of scarified soil was also significantly correlated to calcined clay content ($r = 0.599$, $P \leq 0.0001$) in this study. Calcined clay has been found to increase soil moisture content (30), which may lead to a reduction in surface pace. A more controlled study is needed to explore the effects of scarification depth, calcined clay content, and soil moisture on playing surface pace and hardness.

Conclusions

The hardness of non-turfed basepath surfaces was found to be very high. The United States Consumer Product Safety Commission has stated that athletic field surfaces should not exceed 200 Gmax as measured using the device described in ASTM F355 (3). In this study Gmax was measured using the CIST (2). McNitt (22) reports that the ASTM F355 device and the CIST have the following relationship: F355 = CIST × 1.52 + 9.3. Using this equation, all but three of the non-turfed basepath surfaces tested exceeded this 200 Gmax limit (MLB#1, MLB#2, and NCAA#6). Surfaces with hardness values exceeding this limit have been found to exhibit increased injury potential (17). Future research should explore methods of reducing the surface hardness (Gmax) of these areas that do not negatively affect playability.

Playing surface pace differed by only 7% among the basepath surfaces tested. This consistency reflects how well high-end field managers have done in creating consistent playing conditions by feel alone. The reasons for the small differences in pace are not clear. While surface pace was related to surface hardness in this study, both parameters also correlated to the multiple parameters tested (soil moisture content, scarified soil, etc.). A more controlled study should be undertaken to investigate the effect of these varying surface characteristics on pace.

A potential explanation for the differences in surface pace found in this study may be sub-base soil compaction. Sub-base compaction levels were not measured in this study. Baker et al. (6) found sub-base soil compaction on cricket pitches to be more important in determining the pace of a surface than the moisture content of the uppermost soil layers. Future research should evaluate the effects of sub-base soil compaction and soil moisture on the pace of non-turfed basepath surfaces.

This study is the first to document the playing surface conditions of highly maintained non-turfed basepath surfaces in the northeastern United States. The pace of these surfaces was found to be very consistent from field to field. The hardness of these surfaces was very high and in many cases excessive. The reasons for these conditions were not apparent and more research under controlled conditions is required to determine a stronger cause and effect relationship between surface conditions and baseball field construction and maintenance practices.

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