An Evaluation of Baseball Field Surface Conditions in the Northern United States

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Introduction

The surface condition of any particular baseball field will vary according to a number of different factors. For example, skinned areas can vary based on soil texture and moisture content. Infield surfaces, which can be either natural or artificial in nature, vary as well. Natural turfgrass playing surfaces differ by species, variety, cutting height, moisture content, etc. Artificial surfaces can vary by manufacturer or construction method. These variations can affect the quality of the playing surface. Adverse effects associated with surface quality can jeopardize both the integrity of the game, as well as the safety of the players (Waddington et al., 1997; Rogers et. al, 1993).

The quality of a playing surface can be defined as the suitability of a surface for a particular sport (Baker et. al, 1993). It can be measured or perceived in terms or the interactions between the player and the surface, and the ball and the surface. Certain parameters can have a significant effect on these interactions (Baker et. al, 1993). These parameters include but are not limited to: surface hardness and ball response.

The ability a surface has to absorb energy created by a player upon impact is referred to as surface hardness, or impact attenuation (McNitt, 2000). Playing surface hardness is a key factor in determining field safety, as increased surface hardness has been linked to the potential for lower body injuries (Nigg, 1990; Boden et. al, 2000).

Energy that is not absorbed by the surface upon impact is referred to as ground reaction force (GRF). This energy is returned to the player's body and places a loading stress on the on the system which weakens bones, ligaments, and tendons. Ground reaction forces are involved in the mechanisms of chronic injuries and acute injuries, principally delayed onset muscle soreness and anterior cruciate ligament (ACL) rupture (Boden et. al 2000; LaStayo et. al 2003). Harder playing surfaces that absorb less energy will generate greater ground reaction forces, potentially increasing the incidence of surface related injuries. This demonstrates the importance of surface hardness in determining a field's level of safety.

Ball response is also an important factor in determining a field's level of safety. During a baseball game, the ball will strike the playing surface at a variety of speeds and angles. The speed at which the ball is moving after impact with the playing surface can be referred to as the pace of the surface (Thorpe and Canaway, 1986b). Fields exhibiting excessive pace can jeopardize player safety, and inconsistencies in ball bounce may affect the integrity of the game. The US Consumer Product Safety Commission found that 77 percent of youth baseball injuries result from being struck by the baseball (NYSSF, 2000)

It is well documented that characteristics of both natural and synthetic turf surfaces are greatly influenced not only by surface type but also maintenance procedures, with certain field maintenance procedures commonly being used at all levels of competition. Although these procedures are commonplace throughout the industry, little is known in regards to the degree to which they can alter surface quality. For example, irrigating the skinned portion of the infield will certainly make the surface softer. How much softer will the area play if one was to irrigate at a rate of 10 gallons per 1000 ft^2 compared to 8 gallons per 1000 ft^2? How will this increase in moisture affect the amount of traction experienced by the athlete? Answers to questions of this nature are currently unknown.

The goal of this project was to measure the surface hardness and ball bounce properties of varying baseball field playing surfaces, as well as the surface characteristics that affect them. Average levels of surface playing quality (hardness and pace) were determined and research plots were constructed at the Joseph Valentine Turfgrass Research Center, University Park, PA to represent these averages. Future research will be conducted on these plots in 2006 to explore the degree to which maintenance procedures can affect surface quality.

Materials and Methods

During the 2005 season, a survey was conducted of baseball fields used at all levels of competition, with both natural and infilled synthetic turfgrass fields included in the evaluation. Four Major League Baseball fields (MLB), four minor league baseball field (Professional), six National Collegiate Athletic Association (NCAA), and one municipal field were evaluated. Surface quality (hardness and pace) measurements were made throughout the infield, outfield, and skinned infield portions of each field. Within each one of these locations, smaller sampling zones were selected. Sampling zones consisted of 400 ft^2 areas strategically picked within each location. The infield sampling zones included an area 10 ft in front of homeplate and two areas situated 10 ft inside of the 45 ft mark of the second and third baselines (Figure 1). Outfield sampling zones were located 275 feet off first base and third base, with one zone equidistant between the two (Figure 1). Skinned infield sampling zones were placed 10ft off the first and third bases, with the second base sampling zone centered upon second base (Figure 1).

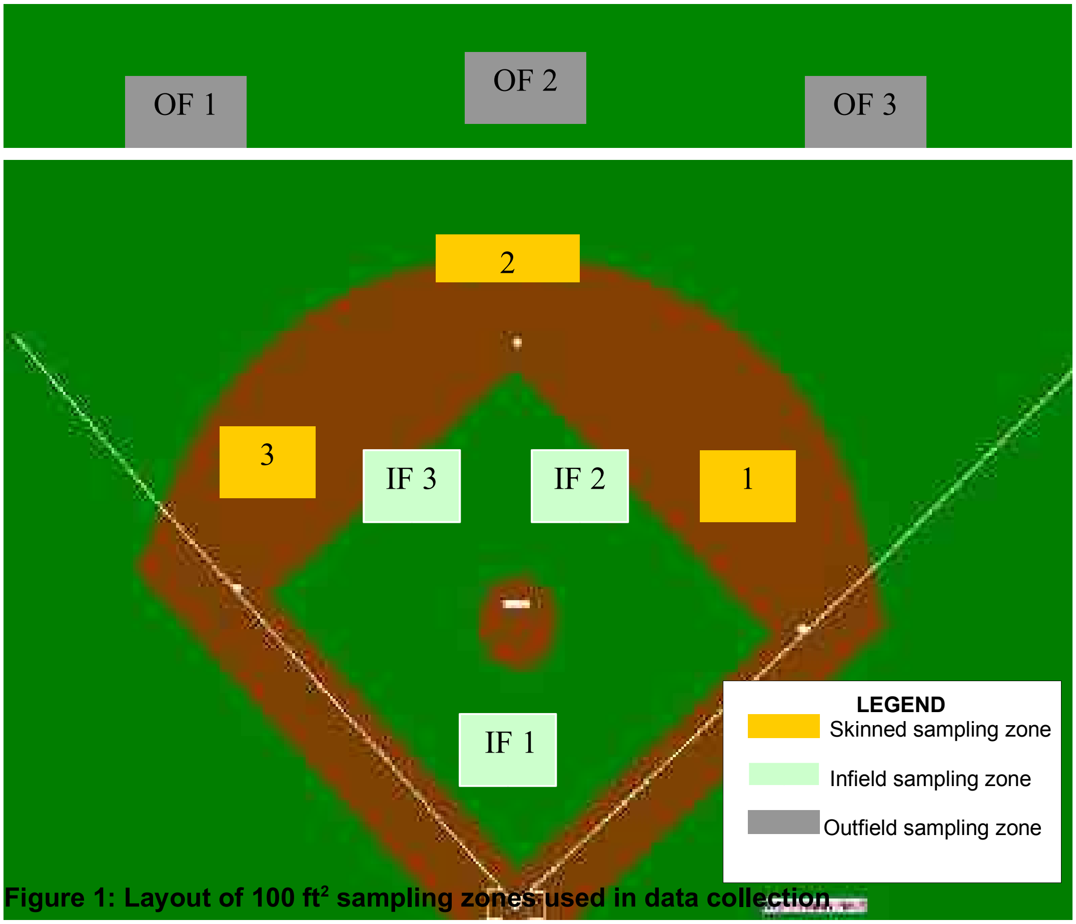

Figure 1: Layout of 100 ft^2 sampling zones used in data collection

Surface hardness measurements were made in each sampling zone. Surface hardness was measured using both a Clegg Impact Soil Tester (Clegg, 1976) (American Society for Testing and Materials, 2000a) and the ASTM F-355 method (American Society for Testing and Materials, 2000b). Impact attenuation, as measured by an accelerometer mounted on the missiles, was used to indicate surface hardness and was reported as Gmax. Gmax is defined as the ratio of maximum negative acceleration on impact in units of gravities relative to the acceleration due to gravity (Henderson et al., 1990). The average of six Clegg measurements and two F355 measurements taken at each sampling zone were used to represent the surface hardness of that sampling zone. A single F355 measurement consisted of dropping the missile three times in the same location, with a three minute interval between each drop. The value reported as Gmax was the average of the second and third drop in the same location.

Playing surface pace was quantified by measuring the coefficient of restitution (COR). The coefficient of restitution 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 (ASTM, 2005a). Coefficient of restitution measurements were attained using an apparatus termed PENNBOUNCE. Preliminary experiments conducted with the device revealed significant differences between various playing surfaces ($p < 0.001$). Measurements were made at a 25º impact angle and a testing velocity of 90 mph (132 ft/sec). Six measurements were conducted within each sampling zone.

Surface characteristics affecting playing quality (hardness and pace) were also measured, using six observations within each sampling zone to represent the average for that zone. For natural turfgrass areas, mowing height, thatch thickness, and volumetric soil moisture content were measured.

Volumetric soil moisture content observations were made using a capacitance probe (Dynamax Inc., Houston, TX). For synthetic surfaces, the depth of infill material was measured, and the manufacturer and age of each surface was also documented. For skinned areas, volumetric soil moisture content, and the depth of loose material (looseness) were measured. Soil texture and particle size analysis was also conducted according the methods described in ASTM F-1632-99 (ASTM, 2005b)

Results

Significant differences were observed between all fields. These differences were a result of a number of different factors including the nature of the materials comprising each surface, management practices, and climate.

Skinned (grass-free) Surfaces

Significant differences were found between all skinned (grass-free) surfaces for the coefficient of restitution, surface hardness (Gmax), volumetric soil moisture content, and depth of loose material (Table 1). Coefficient of restitution measurements ranged from 58.411 % to 51.429 %, indicating that approximately 45% of the velocity of an approaching baseball is lost to the surface on the first bounce at 25 degree angle of inclination. Differences were also observed across the different skinned sampling zones, with coefficient of restitution values lowest at the second base sampling zone (Table 2).

Table 1: Surface quality means for skinned (grass-free) surfaces evaluated in 2005

Field	COR†	Gmax§	Volumetric Moisture Content (%)	Depth of loose material (mm)
MLB #1	54.82 ab*	134.28 f	9.5 f	8.73 cd
MLB #2	52.61 bc	92.71 h	29.9 a	25.07 a
MLB #3	51.43 c	114.77 g	28.3 a	11.87 b
MLB #4	56.60 a	177.46 e	23.1 b	8.22 cde
Professional #1	58.41 a	215.29 b	16.0 de	5.39 gh
Professional #2	57.65 a	132.77 f	24.2 b	6.56 efgh
Professional #3	57.55 a	241.51 a	5.1 g	5.78 fgh
Professional #4	57.48 a	203.62 bcd	8.7 f	6.61 defgh
NCAA #1	55.73 ab	196.41 cd	16.9 d	7.67 cdef
NCAA #2	57.04 a	193.83 cd	16.1 de	7.40 cdefg
NCAA #3	57.31 a	205.34 bc	8.4 f	4.78 h
NCAA #4	57.52 a	215.43 b	14.4 e	6.94 defg
NCAA #5	58.08 a	189.61 de	4.6 g	8.33 cde
NCAA #6	54.88 ab	106.02 gh	19.8 c	11.89 b
Other	56.56 a	145.52 f	22.8 b	9.13 c
Overall Mean	**56.24**	**170.97**	**16.5**	**8.95**

† Coefficient of restitution (COR) = (outbound velocity/inbound velocity) x 100

§ Gmax = the ratio of maximum negative acceleration on impact in units of gravities to the acceleration due to gravity, measured with the Clegg Soil Impact Tester

* Means with different letters are significantly different from one another (Duncan's nMRT, $p \leq 0.05$)

Table 2: Surface quality means for each section of skinned (grass-free) surfaces evaluated in 2005

Base	COR†	Gmax§	Volumetric Moisture Content (%)	Depth of loose material (mm)
First base	56.837 a*	179.58 a	16.5 a	9.478 a
Second base	55.271 b	171.91 b	16.4 a	8.333 b
Third Base	56.678 a	161.45 c	16.6 a	9.062 ab

† Coefficient of restitution (COR) = (outbound velocity/inbound velocity) x 100
§ Gmax = the ratio of maximum negative acceleration on impact in units of gravities to the acceleration due to gravity, measured with the Clegg Soil Impact Tester
* Means with different letters are significantly different from one another (Duncan's nMRT, $p \leq 0.05$)

Gmax values ranged from 245.511 to 92.711, with a mean of 170.97 (Table 1). Gmax values were also significantly different across the skinned infield, with values at the third base sampling zone being lower than those at the first and second base zones, 161.450, 179.577, and 171.910, respectively. (Table 2) Gmax values were highest at the first base zone (Table 2).

Differences in volumetric soil moisture content were also observed between skinned infield surfaces, with values ranging from 29.99% to 4.65%, with a mean of 16.5% (Table 1). No volumetric soil moisture content differences were observed across the different skinned infield sampling zones (Table 2).

Significant differences were also observed when measuring the depth of loose material on the surface. The deepest skinned surface was 25.066-mm and the shallowest was 4.778-mm, with a mean of 8.95-mm (Table 1). Significant differences were also observed across the different skinned sampling zones, with the first and third base sampling zones having more loose material (9.4778 and 9.0620-mm, respectively) than the second base zone of 8.333-mm (Table 2).

Skinned mixes varied in soil texture, particle size, and calcined clay content (Table 3). Samples exhibited an average of 7.963 % gravel, 66.583% sand, 18.147 % silt, 7.308 % clay, and 26.77% calcined clay (Table 3) across the various levels of play. Sand size varied within the sand content of skinned infield mixes also. Significant differences were observed in very coarse sand (2.0-1.0 mm diameter), coarse sand (1.0-0.5 mm in diameter), medium sand (0.5-0.25 mm in diameter), fine sand (0.25-0.15mm in diameter), and very fine sand (0.15-0.05 mm in diameter) (Table 5). Yet, the ratio of coarse particles (gravel and sand) to fines (silt and clay combined) was consistent across mixes, with the percentage of coarse particles in the mix averaging 75% and the percentage of fines in the mix averaging approximately 25% (Table 3)

Table 3: Soil texture† and percent calcined clay of skinned (grass-free) surfaces§ evaluated in 2005

Field	% Gravel	% Sand	% Silt	% Clay	% Calcined Clay
MLB #1	13.213 ab*	76.272 a	9.582 gh	0.933 g	24.02 cde
MLB #2	2.393 fg	67.445 cde	19.452 cd	10.707 b	92.63 b
MLB #3	6.353 def	72.052 b	18.400 cd	3.200 f	100.00 a
MLB #4	5.503 defg	72.575 ab	12.295 fg	9.627 bc	27.47 cde
Professional #1	3.418 fg	60.215 f	29.380 a	6.987 e	0.00 f
Professional #2	7.700 de	70.745 bc	20.997 bc	0.560 g	20.90 cdef
Professional #3	1.500 g	65.817 de	28.178 a	4.506 f	7.02 def
Professional #4	4.642 efg	53.775 g	30.842 a	10.747 b	0.00 f
NCAA #1	16.068 a	68.527 bcde	7.312 h	8.093 cde	0.00 f
NCAA #2	8.937 cd	64.618 e	18.753 cd	7.693 cde	3.76 f
NCAA #3	13.113 ab	59.682 f	14.000 ef	13.200 a	30.75 cd
NCAA #4	5.895 def	56.197 fg	24.215 b	13.693 a	28.65 cde
NCAA #5	3.093 fg	71.708 bc	15.998 de	9.200 bcd	0.00 f
NCAA #6	15.668 ab	69.785 bcd	11.172 fg	3.733 f	0.00 f
Other	11.942 bc	69.332 bcd	11.635 fg	7.093 de	39.08 c
Overall Mean	**7.963**	**66.583**	**18.147**	**7.308**	**26.77**

†Soil texture determined according to the ASTM F1632-03 specification
§ Soil samples collected at a depth of 0.50 inches
* Means with different letters are significantly different from one another (Duncan's nMRT, $p \leq 0.05$)

Table 4: Soil texture† and percent calcined clay for each area of skinned (grass-free) surfaces§ evaluated in 2005

Base	% Gravel	% Sand	% Silt	% Clay	% Calcined Clay
First Base	8.721 a*	66.371 a	18.169 ab	6.739 b	32.01 a
Second Base	7.695 a	66.266 a	18.953 a	7.312 ab	22.78 a
Third Base	7.471 a	67.112 a	17.319 b	7.872 a	25.52 a

†Soil texture determined according to the ASTM F1632-03 specification
§ Soil samples collected at a depth of 0.50 inches
* Means with different letters are significantly different from one another (Duncan's nMRT, $p \leq 0.05$)

Table 5: Particle size analysis† for the sand fraction of skinned (grass-free) surfaces§ evaluated in 2005

	Millimeters in diameter					
Field	**>2.0**	**2.0-1.0**	**1.0-0.5**	**0.5-0.25**	**0.25-0.15**	**0.15-0.05**
	---------------------------------------%---------------------------------------					
MLB #1	13.213 ab*	26.879 c	23.721 a	15.435 bc	7.578 cde	2.657 f
MLB# 2	2.393 fg	26.001 cd	18.942 b	9.525 ef	4.486 fg	8.494 d
MLB #3	6.353 def	43.837 a	13.513 e	5.904 f	3.777 g	5.019 e
MLB #4	5.503 defg	13.807 f	10.207 fg	15.215 bc	18.955 a	14.393 b
Professional #1	3.418 fg	14.605 ef	10.975 f	8.967 ef	6.898 cdef	18.771 a
Professional #2	7.700 de	24.098 cd	15.923 cd	10.444 de	6.800 cdef	13.480 b
Professional #3	1.500 g	10.165 f	10.099 fg	22.438 a	11.624 b	11.492 c
Professional #4	4.642 efg	12.911 f	8.430 g	6.528 ef	6.070 ef	19.835 a
NCAA #1	16.068 a	13.276 f	17.287 bc	21.977 a	9.157 c	6.831 de
NCAA #2	8.937 cd	10.078 f	8.697 fg	23.332 a	11.439 b	11.073 c
NCAA #3	13.113 ab	14.784 ef	14.785 de	18.310 b	6.659 def	5.145 e
NCAA #4	5.895 def	14.975 ef	13.514 e	14.926 bc	6.744 cdef	6.038 e
NCAA #5	3.093 fg	12.416 f	19.017 b	25.464 a	8.915 cd	5.899 e
NCAA #6	15.668 ab	20.393 de	17.053 bcd	13.327 cd	8.106 cde	10.907 c
Other	11.942 bc	35.281 b	17.424 bc	8.035 ef	3.698 g	4.893 e
Overall Mean	**7.963**	**19.567**	**14.639**	**14.655**	**8.060**	**9.662**

Table 6: Particle size analysis† for the sand fraction of each area of skinned (grass-free) surfaces§ evaluated in 2005

	Millimeters in diameter					
Base	**>2.0**	**2.0-1.0**	**1.0-0.5**	**0.5-0.25**	**0.25-0.15**	**0.15-0.05**
	---------------------------------------%---------------------------------------					
First Base	8.720 a*	19.982 a	14.612 a	14.562 a	7.808 a	9.408 a
Second Base	7.470 a	18.719 a	14.836 a	15.115 a	8.021 a	9.575 a
Third Base	7.696 a	20.001 a	14.468 a	14.287 a	8.353 a	10.002 a

†Particle size analysis determined according to the ASTM F1632-03 specification
§ Soil samples collected at a depth of 0.50 inches
* Means with different letters are significantly different from one another (Duncan's nMRT, p≤0.05)

Infilled Synthetic Turf Surfaces

Significant differences were found between all infilled synthetic turf surfaces for the coefficient of restitution, surface hardness (Gmax), and infill depth (Table 7). Coefficient of restitution measurements ranged from 54.919 % to 49.427 %, with an average of 51.97%. Coefficient of restitution values indicated that approximately 48% of the velocity of an approaching baseball is lost to the surface on the first bounce at 25 degree angle of inclination. Coefficient of restitution differences were also observed across the different sampling zones. For all fields evaluated, there were no differences were observed in the mean coefficient of restitution value between the infield and outfield sampling zones. Slight differences were apparent in the mean coefficient of restitution values found between the sampling zones across the entire field (Table 8). Within each individual field, no differences were observed in the coefficient of restitution across the playing surface (data not shown).

Significant differences were observed in surface hardness using both the Clegg Soil Impact Tester as well as the F-355 specification. Gmax values ranged from 77.892 to 51.967, with an average of 66.33 using the Clegg Soil Impact Tester (Table 7). Gmax values derived following the F-355 specification ranged from 148.767 to 106.925 with an average of 136.75 (Table 7). Using both instruments, Gmax values were also significantly different across the field, with values across the infield sampling zones being lower than those in the outfield sampling zones (Table 8).

Table 7: Surface quality means for infilled synthetic surfaces evaluated in 2005

Field	**COR†**	**Gmax§**	**Gmax (F-355)¶**	**Infill Depth (mm)**
MLB #1	51.82 bc*	60.43 b	143.383 a	39.06 b
NCAA #3	54.92 a	77.89 a	143.900 a	26.58 d
NCAA #4	49.43 d	51.97 c	106.925 b	42.50 a
NCAA #5	53.48 e	77.24 a	140.767 a	33.50 c
NCAA #6	50.24 cd	64.14 b	149.767 a	34.81 c
Overall Mean	**51.97**	**66.33**	**136.748**	**35.28**

† Coefficient of restitution (COR) = (outbound velocity/inbound velocity) x 100

§ Gmax = the ratio of maximum negative acceleration on impact in units of gravities to the acceleration due to gravity, measured with the Clegg Soil Impact Tester

¶ Gmax measured according to ASTM F-355 specification

* Means with different letters are significantly different from one another (Duncan's nMRT, $p \leq 0.05$)

Table 8: Surface quality means for each area of infilled synthetic turf surfaces evaluated in 2005

Area	COR†	Gmax§	Gmax (F-355)¶	Infill Depth (mm)
Infield	51.99 a*	63.11 b	135.023 a	35.42 a
IF 1	50.58 b	61.85 c	137.880 ab	34.63 b
IF 2	52.79 a	65.13 bc	135.320 ab	36.76 a
IF 3	52.51 ab	62.35 bc	131.870 b	34.86 b
Outfield	51.96 a	69.55 a	138.473 a	35.15 a
OF 1	51.95 ab	68.38 ab	142.960 a	35.60 ab
OF 2	51.74 ab	67.63 abc	139.320 ab	35.00 b
OF 3	52.30 ab	72.65 a	133.140 b	34.87 b

† Coefficient of restitution (COR) = (outbound velocity/inbound velocity) x 100
§ Gmax = the ratio of maximum negative acceleration on impact in units of gravities to the acceleration due to gravity, measured with the Clegg Soil Impact Tester
¶ Gmax measured according to ASTM F-355 specification
* Means with different letters are significantly different from one another Duncan's nMRT, $p \leq 0.05$)

Significant differences were also observed when measuring infill depth. The deepest infill arrangement was 42.50-mm and the shallowest was 26.58-mm, with a mean depth of 35.28-mm (Table 7). No differences were observed in infill depth between the infield and outfield sampling zones, with slight differences in infill depth found between the sampling zones across the entire field (Table 8).

Natural Turfgrass Surfaces
Significant differences were found between all natural turfgrass surfaces for the coefficient of restitution, surface hardness (Gmax), volumetric soil moisture content, thatch (organic layer), and cutting height (Table 9). Coefficient of restitution values averaged 47.87 % on these surfaces, indicating that approximately 53% of the velocity of a baseball is lost to the surface on the first bounce at 25 degree angle of inclination on natural turfgrass. Coefficient of restitution differences were also observed across the different sampling zones (Table 10). The home plate sampling zone had a higher coefficient of restitution value than the rest of the playing surface (Table 10). Within each individual field, differences were observed in the coefficient of restitution across the playing surface (data not shown).

Table 9: Surface quality means for natural turfgrass surfaces evaluated in 2005

Field	COR†	Gmax§	Volumetric Moisture Content (%)	Cutting Height (in)	Thatch layer (in)
MLB #3	43.21 d*	60.83 b	26.9 b	1.25 d	0.52 b
MLB #4	42.85 d	59.21 b	26.9 b	1.00 e	0.04 de
Professional #1	49.04 c	72.13 a	17.9 d	1.50 b	0.28 c
Professional #2	44.35 d	60.41 b	25.7 b	1.87 a	0.50 b
Professional #3	49.76 bc	71.10 a	22.9 c	1.25 d	0.78 a
Professional #4	44.88 d	60.79 b	22.9 c	1.50 b	0.12 d
NCAA #1	50.98 abc	69.71 a	23.1 c	1.50 b	0.02 e
NCAA #2	52.46 ab	69.44 a	26.1 b	1.31 c	0.05 de
Other	53.34 a	57.89 b	29.4 a	1.53 b	0.85 a
Overall Mean	**47.87**	**64.61**	**24.6**	**1.41**	**0.35**

† Coefficient of restitution (COR) = (outbound velocity/inbound velocity) x 100
§ Gmax = the ratio of maximum negative acceleration on impact in units of gravities to the acceleration due to gravity, measured with the Clegg Soil Impact Tester
* Means with different letters are significantly different from one another (Duncan's nMRT, $p \leq 0.05$)

Table 10: Surface quality means for each area of natural turfgrass surfaces evaluated in 2005

Area	COR†	Gmax§	Volumetric Moisture Content (%)	Cutting Height (in)	Thatch layer (in)
Infield	48.37 a*	69.27 a	25.1 a	1.43 a	0.388 a
IF 1	50.96 a	73.22 a	26.0 a	1.39 bc	0.382 ab
IF 2	48.11 b	68.64 b	24.0 c	1.37 c	0.381 ab
IF 3	47.14 b	65.95 b	23.2 c	1.40 bc	0.400 a
Outfield	47.38 a	59.95 b	24.2 b	1.38 b	0.317 b
OF 1	48.11 b	59.95 cd	24.5 bc	1.43 ab	0.326 abc
OF 2	46.53 b	57.88 d	25.1 ab	1.44 a	0.320 bc
OF 3	47.51 b	62.02 c	25.8 ab	1.45 a	0.305 c

† Coefficient of restitution (COR) = (outbound velocity/inbound velocity) x 100
§ Gmax = the ratio of maximum negative acceleration on impact in units of gravities to the acceleration due to gravity, measured with the Clegg Soil Impact Tester
* Means with different letters are significantly different from one another (Duncan's nMRT, $p \leq 0.05$)

Gmax values measured with a Clegg Soil Impact Tester ranged from 72.125 to 57.894, with a mean of 64.61 (Table 9). Gmax values were also significantly different across the playing surface, with outfield values testing lower than those derived across the infield sampling zones, 59.954 to 69.269, respectively (Table 10). Significant differences in surface hardness were observed at different sampling locations across the field. Left and right field sampling zones had higher Gmax values than the centerfield sampling zone, 62.014 and 59.954 compared to 57.853, respectively (Table 10). Surface hardness values tested highest at the home plate sampling zone, with Gmax values averaging 73.219 (Table 10).

Differences in volumetric soil moisture content were also observed between natural turfgrass surfaces, with values ranging from 29.45% to 17.93% (Table 9). Volumetric soil moisture content differences were observed across the different field sampling zones, with the infield areas measuring lower in moisture content than outfield areas, 24.22% to 25.10% respectively (Table 10). The home plate sampling zone had the highest moisture content of any other zone, with a volumetric soil moisture content of 25.97% (Table 10).

Natural turfgrass surfaces also differed significantly in the amount thatch present. The deepest thatch layer was 0.854-in and the shallowest was 0.020-in (Table 9). Thatch layer differences were observed across the different field sampling zones, with the infield possessing a thicker thatch layer than the outfield, 0.387-in compared to 0.317-in respectively (Table 10).

Differences in cutting height were also observed between natural turfgrass surfaces, with values ranging from 1.875-in to 1.000-in (Table 9). Cutting height differences were observed across the different field sampling zones, with the infield possessing a lower average cutting height than the outfield, 1.385 to 1.439-in respectively (Table 10).

Discussion

Skinned Surfaces

The infield mix with the fastest pace had a coefficient of restitution value of 58.411 %, while the slowest surface had a coefficient of restitution of 51.429 % (Table 1). This translates into the ball reaching the player at approximately a 7% slower velocity. A velocity change of this magnitude allows the player to travel approximately one foot further to reach an approaching ground ball. This small difference can drastically affect a game, as it could potentially serve as the difference between a ground ball being fielded adequately or traveling past an infielder into the outfield.

Differences in surface pace (coefficient of restitution) values were observed across skinned infield soil mixes used at varying levels of competition. The mixes were significantly different in sand, silt and clay content from one another, yet the relative ratio between coarse (gravel and sand) and fine particles (silt and clay) was similar in all mixes evaluated. Mixes contained 75% coarse particles (gravel and sand) and 25% fines on average (Table 3). This similarity between the skinned mixes suggests that other factors are responsible for variations in surface hardness and pace, principally surface characteristics altered through maintenance procedures.

Gmax values were extremely high when looking across a wide range of mixes and moisture contents, with an overall mean of 170.978 (Table 1). Surfaces of this nature, those with Gmax values approaching 200, have been found to exhibit increased injury potential (ASTM 2000c), and often require re-surfacing due to the fact that little energy is absorbed by the surface. The majority of this energy is returned to the athlete's body in the form of ground reaction force.

This ground reaction force places a loading stress on the on the body which weakens bones, ligaments, and tendons. Increased ground reaction force is indicated as a factor in the onset of chronic (wear and tear) type injuries (LaStayo et. al, 2003). Upon striking the surface, the quadriceps muscles undergo an eccentric muscle contraction to balance the ground reaction force exerted onto the body. These contractions stretch muscle fibers often leading to the soreness and pain associated with chronic injuries. This is highly important as majority of injuries in baseball can be classified as chronic in nature (Dick, 2005).

Gmax values also varied across the different skinned infield sampling zones. The first base sampling zone had the highest Gmax value (179.577), while the second base zone had the second highest (171.910), and third base had the lowest Gmax value (161.450) (Table 2). This is likely related to soil compaction. More runners reach first base than any other base on the diamond. Thus, the soil is subject to traffic from both the fielder and the runner, likely causing Gmax values to be higher.

The reason for the observed differences in playing surface pace is not clear. For example, the skinned surface of Professional field #2 and NCAA field #5 had drastically different Gmax and moisture content values. Professional field #2 registered a Gmax value of 132.767 and 24.27% moisture content, while NCAA #5 registered a Gmax of 189.611 and 4.65% moisture (Table 1). Many field managers feel that applying moisture will affect the pace of the playing surface. If moisture content was the key factor in determining the pace of the skinned surface, Professional field #2 would have had a slower pace (lower coefficient of restitution) than NCAA #5, yet the two fields did not have significantly different coefficient of restitution values, 57.654 and 58.078, respectively (Table 1).

The reason for the similar ball response may be due to the fact that the sub-base layers of both fields were compacted to a similar degree. Regardless of the content of the material on the surface (i.e. – calcined clay), the ball works through this loose material and "bottoms out" with the sub-base below. As previously indicated, this base layer is often a highly trafficked compacted soil that doesn't receive any compaction relief. Applied moisture will likely not doing anything to soften the sub-base layer, as infiltration into highly compacted clay soils has been proven to be very slow. Applying water will likely just maintain the structural integrity of the loose layer above, and not infiltrate into the compacted sub-base. Testing equipment will only measure moisture content in the upper layers of the profile, not the sub-base. This could potentially explain why skinned surfaces with very different moisture contents exhibit a similar ball response.

Future research is needed to determine the volume of water needed to effectively soften the compacted sub-base layer common to skinned surfaces.

Infilled Synthetic Turf Surfaces

Significant differences were found in surface pace across infilled synthetic turf surfaces. The infilled surfaces with the fastest pace had a coefficient of restitution values of 54.912% (Table 7), while the slowest surface had a coefficient of restitution of 49.427 % (Table 7). As with skinned surfaces, this translates into the ball moving forward at a slower velocity, and thus allowing the player to travel further to reach an approaching ball. Again, this small difference can drastically affect a game, as it could potentially serve as the difference in whether or not a ground ball is fielded adequately.

Differences in surface pace were associated with surface hardness (Gmax) and infill depth. Harder surfaces will absorb less energy, thus returning more energy to the ball after impact. This will potentially allow for the velocity of the ball after impact to be greater, which will in turn generate a higher coefficient of restitution value. Increasing the amount of loose material will not only soften the surface, but similar to skinned surfaces, provide the ball with a thicker layer to travel through before impact.

Surface pace within each individual infilled synthetic turf system was very consistent, with no significant differences in pace apparent at different locations across the playing surface (Data not shown). This consistent pace was only evident on fields that were greater than one year of age. An evaluation of the total number of errors made on infilled synthetic turf systems in Major League Baseball from 2002 through 2004, discovered that significantly less errors were made on infilled synthetic turfgrass systems compared to cool season turfgrass fields (James, 2005). Consistent pace is likely a factor in the reduced error rate which was observed. Fields younger than one year of age did not exhibit a consistent pace across the playing surface. Likely, it takes approximately a year of time for loose rubber and sand infill material to settle into the carpet and form a uniform layer with which the ball can react with upon impact.

While consistent pace was observed across the playing surface of each individual infill system, this was not the case when evaluating infill systems as a group. Differences were found in surface pace and Gmax when comparing different field locations. For example, infield surface were softer than outfield surfaces, showing Gmax values of 69.554 and 63.111 respectively, when measured with a Clegg Soil Impact Tester (Table 8). Among outfield areas, the centerfield sampling zone tended to be softer than the left and right field zones, as measured with both the Clegg Soil Impact Tester and the F-355 apparatus (Table 8). The nature of the game of baseball lends itself to centerfielders being more mobile than the left and right fielders. Due to the fact that centerfielders are not stationary as much as the other outfielders the compaction of the infill material may be lessened enough to produce a softer surface.

Natural Turfgrass Surfaces
Significant differences in surface pace were observed across different natural turfgrass playing surfaces. The natural turfgrass surface with the fastest pace had a coefficient of restitution value of 53.339 %, the slowest surface had a coefficient of restitution of 42.853%, and the mean coefficient of restitution was 47.87% (Table 9). This difference between the fastest and slowest surfaces translates into the ball reaching the player at approximately a 9% slower velocity, thus allowing the player additional time to field and approaching ground ball. This small difference can drastically affect a game’s outcome. Baseballs striking natural turfgrass surfaces lost approximately 53% (Table 9) of their initial velocity upon impact at a twenty five degree angle of inclination. This is significantly more than infill and skinned surfaces at the same angle of inclination. Balls striking infill systems lost approximately 48% of their initial velocity (Table 7) and those striking skinned surfaces lost approximately 43 % (Table 1)

These observed differences in surface pace were associated with certain surface characteristics including surface hardness (Gmax), moisture content, and the thickness of the thatch layer As with both skinned and infilled synthetic surfaces, a harder surface will absorb less energy, thus returning more energy to the ball after impact. This will potentially allow for the ball’s velocity after impact to be greater, giving rise to a higher coefficient of restitution value.

The role the thatch layer played in determining the pace of a natural turfgrass playing surfaces was interesting. Thatch is a layer of organic material that sits above the hard soil base layer (Beard, 1973). The ball needs to travel through this layer to contact the base layer below. Yet unlike skinned soil and infill turf surfaces, increases in the thickness of the impeding layer were associated with increased surface pace. Organic layers, unlike the loose material associated with skinned and infilled surfaces, are a cohesive unit of connected materials. This gives the layer elasticity that may be allowing a springboard effect to occur, generating a faster velocity after impact. More research is needed to explore this issue.

Differences were found in surface hardness across each natural turfgrass field. Infield surfaces were found to be significantly harder than outfield surfaces, 69.26 compared to 59.54, respectively (Table 10). This difference in surface hardness could potentially be due to a number of factors. Infields are often topdressed with sand and rolled in an effort to smooth the surface in order to achieve a consistent ball response. Topdressing with sand and subsequent rolling is commonly associated with increasing the surface hardness of golf course putting greens (Beard, 1973). Traffic patterns could be another factor, along with repeated ball to surface impacts from batting practice session. As with infill systems, the centerfield area of the outfield was softer than both left and right field, 57.883 compared to 59.954 and 62.024, respectively (Table 10). Again, this is likely because left and right fielders traditionally are stationary for longer periods of time during a game than centerfielders.

Applications of water will serve to lower surface hardness and thus reduce the velocity of the ball after impact. Outfield surfaces were found to have significantly higher volumetric moisture contents than infield surfaces, 25.10% compared to 24.24%, respectively (Table 10). This could potentially be due to the fact the infield turfgrass is covered by a tarp during periods of rain while the outfield is left exposed. Within the infield, the sampling zone in front of home plate had the highest moisture content, 25.970% (Table 10). This is likely due to the fact that field managers often water down this area, as well as the home plate skinned cutout, to reduce the velocity of the baseball after impact.

Conclusion

Surface characteristics were found to have a significant effect on the safety and quality of baseball fields. The hardness of the playing surface, particularly the skinned soil areas, often reached unsafe levels, to that point that increases in the frequency of injuries may be likely. A key component of playing quality is consistent playing surface pace. Variation in maintenance procedures likely resulted in differences in playing surface pace observed in this evaluation. More research is being conducted at the Joseph Valentine Turfgrass Research Center, University Park, PA to explore these issues in detail.

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