Journal of Testing and Evaluation, Vol. 39, No. 3
Paper ID JTE103215
Available online at: www.astm.org

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Effects of Surface Conditions on Baseball Playing Surface Pace

ABSTRACT: The speed at which a baseball travels after impact with a playing surface has been referred to as playing surface pace. Little information is available regarding the effects of varying construction and maintenance practices on the pace of baseball playing surfaces. Research was conducted to evaluate the effects of construction and maintenance practices on a non-turfed basepath, Kentucky bluegrass (*Poa pratensis* L.) turf, and six synthetic turf surfaces. Factors evaluated on the non-turfed basepath included soil compaction at installation, surface scarification, and topdressing with a soil conditioner (calcined clay). The effects of cutting height and thatch thickness were evaluated on Kentucky bluegrass, while the effects of simulated traffic and grooming were evaluated on synthetic turf. On the non-turfed basepath, increasing soil compaction yielded increases in surface pace. Calcined clay topdressing and increasing scarification depth did not affect surface pace. On Kentucky bluegrass, varying cutting height and thatch thickness levels had no effect on surface pace. On synthetic turf, increases in simulated traffic resulted in slight increases in pace. Surface pace measurements on synthetic turf were less variable than those made on natural turfgrass. The results indicate that the pace of commonly used baseball playing surfaces is not easily altered with minimally invasive maintenance procedures and should be addressed at construction or during aggressive renovations.

KEYWORDS: coefficient of restitution, COR, bounce, turfgrass, playing surface pace, Pennbounce

Introduction

Over 10 million people in the United States play baseball annually [1]. Baseball playing surface quality can affect both player safety and the integrity of competition [2]. Athletic field playing quality has been defined as the suitability of a playing surface for a particular sport, including how the surface interacts with both the player and the ball [3].

Baseball playing fields often contain more than one surface type. Most contain a bare-soil playing surface (non-turfed basepath), in addition to a natural or synthetic turf surface covering the remainder of the field. During a baseball game, the ball strikes these playing surfaces at a variety of speeds and angles. The speed at which a ball is moving after an impact with a playing surface has been referred to as the pace of the surface [4]. When surface pace increases to the point where the speed of an approaching ball exceeds a player's reaction time, competing athletes are more likely to be struck with the approaching ball [5]. Inconsistencies in pace across a field can reduce the safety and playability of the surface, as athletes are more likely to misjudge the speed and trajectory of the bouncing ball.

Typically, playing surface pace has not been measured directly but has been inferred from measurements of vertical ball rebound conducted via vertical drop tests [3,6]. Stewart and Adams [7] and Drury [8] reported that vertical drop test results were correlated with players' opinions of pace recorded using post-game surveys. Adams et al. [4] found visual estimates of cricket pitch pace by umpires to be unreliable, as they were confounded by the angle at which the ball traveled after impact with the surface.

Goodall et al. [9] estimated pace by measuring the static and dynamic frictional properties of five soil mixes commonly used on non-turfed basepaths. Static ball-to-surface friction was measured using a modified version of the studded disk traction apparatus developed by Canaway and Bell [10]. Dynamic ball-to-surface friction was measured using a pendulum apparatus. Goodall et al. [9] found that both static and dynamic ball-to-surface friction increased as soil texture became finer and soil moisture content increased. The addition of calcined clay as a soil amendment decreased static and dynamic ball-to-surface friction. Goodall et al. [9] suggested that a decrease in static and dynamic friction would lead to an increase in surface pace.

Baker et al. [11] quantified playing surface pace directly by measuring the coefficient of restitution (COR). The COR is defined as a ratio of two velocities: the velocity of a baseball after impact with the surface divided by the velocity of the ball prior to impact [12]. Baker et al. [11] reported a range of COR values on cricket pitches of 0.75–0.91. Adams et al. [4] reported a narrower range of COR values (0.834–0.907) on 23 cricket pitches in the United Kingdom. Both Adams et al. [4] and Baker et al. [11] reported that surface pace increased with increasing soil bulk density and decreased with increasing soil organic matter, soil moisture, and silt and clay content. Baker et al. [11] observed variations in pace (COR) on cricket pitches of the same soil moisture content and texture and surmised that the hardness of the underlying sub-base material (below 100 mm) may have a larger effect on playing surface pace (COR) than the moisture content of the soil surface layer.

After surveying professional baseball fields, Brosnan and McNitt [13,14] reported that baseball surfaces varied in COR. Non-turfed basepaths yielded the highest COR (0.562), natural turfgrass surfaces yielded the lowest COR (0.479), and synthetic turf surfaces ranked intermediate (0.520). Additionally, Brosnan and McNitt [14] noted that COR measurements were more consistent on synthetic turf playing surfaces compared to natural turfgrass. The researchers suggested that COR measurements on natural turfgrass surfaces may be affected by variations in cutting height and soil moisture content, while those on synthetic surfaces may be due to

Manuscript received June 19, 2010; accepted for publication September 14, 2010; published online October 2010.

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differences in the material properties of the fibers, backing, and rubber infill comprising each surface. Similar to the observations of Baker et al. [11], Brosnan and McNitt [13] hypothesized that COR measurements on non-turfed basepaths may be affected more by sub-surface soil compaction than the range of moisture contents measured in the uppermost soil layers of professional baseball fields.

Objective

The effect of varying surface conditions on the pace of the different baseball field playing surfaces currently in use has not been measured directly in a controlled study. The objective of this project was to determine the effect of varying surface conditions on the pace of baseball playing surfaces, including non-turfed basepaths, natural turfgrass, and synthetic turf.

Materials and Methods

Four experiments were conducted to determine the effects of varying surface conditions on non-turfed basepath soil, natural turfgrass, and synthetic turf. All four experiments were conducted at the Joseph Valentine Turfgrass Research Center, University Park, PA. Plots were constructed in an attempt to span the range of conditions reported in a baseball field survey conducted by Brosnan and McNitt [13,14].

Plot Construction and Experimental Design

Non-Turfed Basepath Experiment—Nine 37.2 $\times 37.2\ m^2$ plots were constructed to a depth of 10 cm using Diamond-Tex Premium infield mix (Diamond-Tex, Inc., Honeybrook, PA). Particle size analysis of the infield mix was 10 % gravel, 56 % sand (16 % of particles 2.0–1.0 mm; 9 % of particles 1.0–0.5 mm; 8 % of particles 0.5–0.25 mm; 6 % of particles 0.25–0.15 mm; 17 % of particles 0.15–0.05 mm), 27 % silt, and 7 % clay [15]. For a more detailed description of plot construction, see Brosnan et al. [16].

Brosnan and McNitt [13] surmised that surface pace (COR) measurements on non-turfed basepaths may be affected by the compaction of the sub-base soil layer, the depth of loose material on the soil surface, and the amount of soil conditioner (calcined clay) applied as a topdressing. Those factors served as treatments in this study. Treatments were oriented in a strip-split plot design. Soil compaction served as the whole plot treatment. Compaction treatments were applied with a 907 kg roller pulled by a Ventrac tractor (Model 4200 VXD, Ventrac, Inc., Orrville, OH) with a dual turf tire package. Plots were rolled in order to achieve soil bulk densities of ~ 1.8, 1.5, and 1.2 $Mg \cdot m^{-3}$ on high, medium, and low compaction plots, respectively. Bulk density measurements were made with a Troxler surface moisture density gauge (Troxler Electronic Laboratories, Research Triangle Park, NC) according to the methods of Gardner [17].

Whole plots were divided into four $1.5 \times 1.5\ m^2$ subplots that received applications of calcined clay (heat treated, 649°C, 74 % SiO_2, average diameter of 1.18 mm; Turface MVP, Profile Products, Buffalo Grove, IL) at four rates: 0, 4883, 9767, and 14 650 $kg\ ha^{-1}$ with a drop spreader (Model 36, Gandy Co., Owatonna, MN).

Each block was divided into $1.5 \times 6.1\ m^2$ strips that ran across all whole plots. Each strip received a different scarification depth treatment (0, 6.5, 12.7, and 19.0 mm). Scarification depth treatments were applied with a nail drag apparatus constructed according to the procedures outlined in ASTM F-2107-01 [18]. The nail drag apparatus was pulled across the surface of each plot until the soil was loosened to desired scarification depths (0, 6.5, 12.7, and 19.0 mm). Scarification depths were measured using a point gauge. The gauge consisted of a pointed metallic rod attached to a ruler. The rod was inserted into the loose soil until contacting the compacted sub-base. The depth of penetration was recorded. The average of nine measurements was used to represent the scarification depth of each plot.

Natural Turfgrass Experiment—Natural turfgrass plots, $18.6 \times 18.6\ m^2$ in size, were constructed using thick cut (44 mm) Kentucky bluegrass (*Poa pratensis*, L.) big roll sod (40 % "P-105," 30 % "Midnight Star," 30 % "Brilliant") harvested from a sandy soil (92.4 % sand, 4.5 % silt, 2.8 % clay) in Fall 2005 and installed over a tilled and leveled Hagerstown silt loam soil (fine, mixed Mesic Typic Hapludalf).

Thatch layer thickness and cutting height served as treatments in this study. Treatments were arranged in a strip-plot design, with thatch thickness serving as the whole plot treatment and cutting height serving as the strip-plot treatment. Thatch treatments were applied by subjecting plots to various numbers of passes with a vertical mower (Sensation, Model No. 18720, Plymouth, WI) set to different depths on April 25, 2006. Ten plugs were removed from each whole plot on June 22, 2006, and thatch thickness was measured under a 479 g weight [19]. High thatch plots averaged 18.9 mm, medium plots averaged 12.8 mm, and low thatch plots averaged 4.0 mm.

Whole plots were split into strips of three cutting heights: 3.8, 5.1, and 6.4 cm. Strips were $1.0 \times 6.1\ m^2$ in size, and mowed two times per week with a Craftsman rotary mower (Model No. 917387500, Chicago, IL). Clippings were returned to the surface during mowing.

Synthetic Turf Experiments—Synthetic turf plots had previously been installed at the Joseph Valentine Turfgrass Research Center, University Park, PA, in Fall 2002. For a more detailed description of plot construction, see McNitt [20].

Two synthetic turf studies were conducted: A pre-grooming and post-grooming experiment. In each, six synthetic turf systems were evaluated: Fieldturf (FTOS1-F, Dalton, GA), Sportexe ("Omnigrass-41," and "Omnigrass-51," Round Rock, TX), Sprinturf (Wayne, PA), Sofsport (Lancaster, PA), and Astroturf (SRI Sports, Dalton, GA). Three replications of each synthetic turf system were arranged in separate completely randomized designs for the pre- and post-grooming experiments.

Plots in each experiment were split with varying levels of simulated traffic. Traffic was applied with a Brinkman Traffic Simulator [21] pulled by the previously described Ventrac tractor.

Two levels of traffic were evaluated on synthetic turf plots: No traffic and high traffic (eight passes, three times per week, totaling 24 passes for an entire week). High traffic plots received 24 passes per week (12 games) until a total of 96 simulated games had been applied. Once all data had been collected following traffic application, plots were groomed with a power broom (Shindaiwa, Model PB270, Tualatin, OR) and a 102 cm lawn, star-shaped, spike-type aerator (Model No. 45-0296, Agri-fab, Inc., Sullivan, IL) in order to loosen rubber infill granules and to return synthetic fibers to an upright position. This marked the start of the post-grooming experiment.

Data Collection

Playing Surface Pace—Playing surface pace was quantified by measuring the COR in the non-turfed basepath, natural turfgrass, and synthetic turf experiments. An apparatus, termed Pennbounce, was used to measure the COR [22]. The apparatus was implemented with infrared screens placed 305 mm from the testing surface. These screens measured the velocities of baseballs, propelled by an air cannon (Model No. Storm 300, Air Cannon, Inc., Denver, CO), before and after striking the surface. Measurements were made at a 0.44 rad impact angle and testing velocity of 40.2 $m \cdot s^{-1}$, as previous research found this configuration to best represent ball-to-surface interactions on baseball field playing surfaces [22]. The average of three COR measurements was used to represent the COR of each subplot.

Volumetric Soil Moisture Content and Soil Bulk Density—Volumetric soil moisture content and soil bulk density were measured as part of the non-turfed basepath and natural turfgrass experiments using a Troxler 3400-B soil moisture density gauge according to the methods of Gardner [17]. On natural turfgrass plots, measurements of volumetric soil moisture content and soil bulk density were taken with the probe of the Troxler guage inserted into the profile to a depth of 5.08 cm below the surface. On non-turfed basepath plots, the Troxler was used to collect data using the probe in back-scatter mode.

Statistical Analyses

Non-Turfed Basepath Experiment—Data were collected on non-turfed basepath plots two times in 2006 (April 27–May 2 and July 16–July 21) and analyzed using analysis of variance in SAS [23]. No interactions between sampling period (time) and treatments were detected (except where noted), so only pooled means are reported. Fisher's protected least significant difference (LSD) test ($\alpha = 0.05$ level) was used to separate treatment means [23].

Natural Turfgrass Experiment—Data were collected on natural turfgrass plots from June 28 through July 6, 2006. All data were analyzed using analysis of variance and Fisher's protected LSD test at the $\alpha = 0.05$ level [23].

Synthetic Turf Experiment—Data for the pre-grooming experiment were collected on synthetic turf plots from July 6 to July 11, 2006. Plots were groomed on Aug. 24, 2006, and surface pace data were collected again for the post-grooming experiment from Aug. 25 to Sept. 9, 2006. Data collected in the pre- and post-grooming experiments were analyzed separately using analysis of variance and Fisher's protected LSD test at the $\alpha = 0.05$ level [23].

Overall Comparison of Surfaces for Variability—Variability in surface pace was determined on all surface types. Variability was determined by measuring the percent range of COR values on each surface type using the equation % range $= \{[\text{maximum COR value} - \text{minimum COR value}] \div \text{maximum COR value}\} \times 100)$ [24]. Three measurements were averaged to represent the mean for each subplot. Subplot means were then averaged to create an overall surface mean. Overall surface means for non-turfed basepaths, natural turfgrass, and synthetic turf were compared using two sample *t*-tests [23].

TABLE 1—*Mean surface pace values for the soil compaction by time interaction.*

	Surface Pace[a]	
	Time 1	Time 2
Soil Compaction Level	COR	
High	0.543	0.589
Medium	0.525	0.573
Low	0.442	0.527
$LSD_{0.05}$	0.013	0.012

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

Results and Discussion

Non-Turfed Basepath Experiment

Playing surface pace (COR) of non-turfed basepath plots was affected by soil compaction treatments (Table 1). COR values ranked highest, lowest, and intermediate on the high, low, and medium compaction treatments, respectively, during both sampling periods (Table 1). Higher COR values are likely the result of an increase in soil bulk density due to the soil compaction treatments (Table 2). Plots receiving the high, medium, and low soil compaction treatments yielded soil bulk densities of 1.63, 1.54, and 1.46 $Mg \cdot m^{-3}$, respectively (Table 2).

No soil moisture differences were detected between plots receiving high and medium levels of soil compaction; however, both measured lower in soil moisture content than the low soil compaction treatment (Table 2). The overall range of soil moisture content values between treatments was small, ranging from 0.143 to 0.122 $m^3 \cdot m^{-3}$.

The surface pace (COR), soil bulk density, and soil moisture data shown in Tables 1 and 2 support the assumptions of Baker et al. [11], that cricket pitch pace is affected to a greater degree by the bulk density of underlying soil layers (below 100 mm) than the moisture content of the surface soil. In this study, increasing soil

TABLE 2—*Mean soil bulk density and soil moisture content values for soil compaction levels measured on non-turfed basepath plots.*

Soil Compaction Level	Soil Bulk Density[a] $Mg \cdot m^{-3}$	Soil Moisture Content[b] $m^3 \cdot m^{-3}$
High	1.63	0.122
Medium	1.54	0.131
Low	1.46	0.143
$LSD_{0.05}$	0.07	0.017

[a]Bulk density measured with a Troxler 3400-B series moisture density gauge.
[b]Volumetric soil moisture content measured with a Troxler 3400-B series moisture density gauge.

TABLE 3—*Mean surface pace values for calcined clay treatments applied to non-turfed basepaths in 2006.*

	Surface Pace[a]	
Calcined Clay Rate	Time 1	Time 2
$kg \cdot ha^{-1}$	COR	
0	0.506	0.568
4883	0.508	0.562
9767	0.498	0.561
14 650	0.502	0.561
$LSD_{0.05}$	NS	NS

Note: NS=not significant.

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

TABLE 4—*Treatment main effects and interactions for surface pace data collected on synthetic turf plots.*

		Surface Pace[a]	
Source	DF	Pre-Grooming Experiment	Post-Grooming Experiment
Surface (*S*)	5	***	***
Traffic (*T*)	1	*	NS
$S \times T$	5	NS	NS
Error	96	⋯	⋯

Note: NS=not significant.

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

*Significant at $p \leq 0.05$ level.

***Significant at $p \leq 0.001$ level.

bulk densities resulted in increasing surface pace. The range in moisture content of the surface soil was small and did not affect COR (Tables 1 and 2).

Calcined clay treatments had no effect on COR in this study (Table 3). COR values for plots receiving 0 and 14 650 $kg\ ha^{-1}$ of calcined clay averaged 0.506 and 0.502 during the first sampling period and 0.568 and 0.561 during the second sampling period, respectively (Table 3). These results differ from the work of Goodall et al. [9], who reported that increasing concentrations of calcined clay reduced both static and dynamic ball-to-surface friction, which they surmised would lead to an increase in playing surface pace.

Differences between the two studies are likely due to differences in evaluation methods. Goodall et al. [9] estimated surface pace indirectly from measurements of ball-to-surface friction. In this study, surface pace was measured directly using Pennbounce. Additionally, the devices used by Goodall et al. [9] measured the ball-to-surface interactions at velocities much lower than those experienced during actual play, while Pennbounce measured ball-to-surface interactions at velocities similar to those experienced during play [22]. Due to the higher testing velocities, balls likely had enough energy to interact with the soil sub-base layer to a greater degree when measured using Pennbounce as opposed to the Goodall et al. [9] devices, which will likely be more affected by the loose material on the soil surface.

Natural Turfgrass Experiment

For the natural turfgrass experiment, no differences in surface pace (COR) were detected between thatch thickness or cutting height treatments. COR values for the natural turfgrass experiment averaged 0.445(+/−0.061), and since all data were non-significant, they are not shown. These results differ from those reported by Brosnan and McNitt [14] who found that thatch thickness significantly correlated with COR when measuring the pace of baseball surfaces in different stadiums.

The thatch thickness and cutting height differences reported by Brosnan and McNitt [14] were likely the result of varying maintenance practices used on different baseball stadium surfaces. These surfaces also likely had varying soil types and varying soil bulk densities. The lack of differences due to treatments in this study where all treatments were on the same soil and subjected to the same maintenance practices suggests that playing surface pace on natural turfgrass may be affected to a greater degree by soil type and sub-surface soil compaction than by the range of cutting height and thatch thickness differences examined in this study. More research is needed to parse these effects to a greater degree.

Synthetic Turf Experiment

Differences in COR values were detected among the synthetic turf surfaces in both the pre-grooming and post-grooming experiments. The traffic treatment affected COR in the pre-grooming experiment as well (Table 4). The surface-by-traffic treatment interaction was not significant in either experiment.

For the pre-grooming experiment, COR values averaged 0.560 and 0.524 on plots receiving and not receiving traffic, respectively. The traffic treatment may have compacted the infill material and caused COR values to increase. Infill compaction was not measured in this study. The traffic treatment had no effect on surface pace (COR) in the post-grooming experiment (Table 4); reasons for this difference are not clear from this study. Future research evaluating the effects of grooming on synthetic turf surfaces subjected to traffic is warranted.

In both experiments, the surface pace was highest on Astroturf and lowest on Omnigrass-41 (Table 5). Variation among surfaces in COR may have been a function of infill depth, as surface pace COR and infill depth were significantly correlated ($r=-0.598$, $p \leq 0.001$).

TABLE 5—*Mean surface pace values measured on synthetic turf surfaces before and after grooming.*

	Surface Pace[a]	
	Pre-Grooming Experiment	Post-Grooming Experiment
Surface	COR	
Astroturf	0.599	0.631
Fieldturf	0.514	0.533
Sofsport	0.527	0.530
Sprinturf	0.551	0.559
Omnigrass-41	0.508	0.529
Omnigrass-51	0.554	0.536
$LSD_{0.05}$	0.026	0.031

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

TABLE 6—*Consistency of surface pace (COR) values measured on non-turfed basepath, natural turfgrass, and synthetic turf playing surfaces.*

Surface Type	*N*	Range[a]
Non-turfed basepath	1296	55.6
Natural turfgrass	108	55.0
Synthetic turf	216	39.5
Before grooming	108	36.9
After grooming	108	42.2

[a]% Range=[(maximum COR value−minimum COR value)/maximum COR value]*100.

Variability of Coefficient o Restitution Values among Experiments

The variability of COR values obtained on natural turfgrass and non-turfed basepath plots were similar (~55%) (Table 6). COR values on synthetic turf plots were less variable, ranging by only 39.5 % (Table 6). COR variability on synthetic turf plots was found to be significantly lower than natural turfgrass and non-turfed basepath plots using separate two sample *t*-test ($p < 0.002$).

Conclusion

Soil compaction was the only experimental factor that affected surface pace on non-turfed basepaths in this study. The results confirm the hypotheses of Brosnan and McNitt [13] and Baker et al. [11] that soil compaction has a larger effect on surface pace than the moisture content of the uppermost soil layer and the use of calcined clay as a soil conditioner. Within the ranges evaluated in this study, neither calcined clay nor scarification depth affected surface pace on non-turfed basepaths. On natural turfgrass, the varying cutting height and thatch thickness levels used in this experiment had no effect on the playing surface pace. The results of this and prior studies suggest that the physical properties of the rootzone probably have a greater influence on the playing surface pace of natural turfgrass than the cutting height and thatch thickness differences examined in this study. Surface pace measurements on synthetic turf surfaces in this study were less variable than those made on natural turfgrass.

Baseball field managers attempting to affect the pace of a field through minimally invasive maintenance practices targeted at the playing surface (i.e., scarification of non-turfed basepaths, manipulating cutting height, grooming synthetic turf, etc.) will likely be unsuccessful. The results of this study indicate that significant changes in the pace of these baseball playing surfaces are best accomplished by altering the bulk density of the soil below the surface in the case of natural turfgrass and non-turfed basepaths, and perhaps changing the infill depth on synthetic turf systems. Practices of this nature would commonly be implemented at construction or during an aggressive renovation.

Acknowledgments

The writers would like to thank the Pennsylvania Turfgrass Council for their financial support. Additionally, the writers would like to thank Diamond-Tex, Inc., Profile Products, and Tuckahoe Sod Co. for generously donating materials used for plot construction. Dr. Max Schlossberg, Mr. Dave Livingston, and Ms. Dianne Petrunak also aided greatly in the completion of this project.

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