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Ball Response and Traction of Skinned Infields Amended with Calcine Clay at Varying Soil Moisture Contents

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ABSTRACT

The skinned portions of baseball and softball infields vary widely with respect to soil texture, applied amendments and conditioners, and water management. No studies have been reported that quantify the effects of these varying construction and maintenance practices on the playability of the skinned portions of infields. In Connecticut, USA, skinned infield plots were constructed from five different soils (silt loam, loam, coarse sandy loam, loamy sand, loamy coarse sand) and amended with four rates of calcined clay (0, 4.9, 9.8, 19.6 kg m^{-2}) to determine the effects on surface hardness, traction, and ball-to-surface friction (static and dynamic) at varying soil moisture contents (10, 14, and 18%). Bulk density, saturated hydraulic conductivity, and shear strength of the different soil–calcined clay rate combinations were determined. Increasing the rate of calcined clay decreased bulk density and shear strengths, and increased saturated hydraulic conductivity. Surface hardness increased more with coarse-textured soils and increasing calcined clay rate, but decreased more with fine-textured soils and increasing soil moisture. Increasing the calcined clay rate resulted in decreases in ball-to-surface static friction across all soils and decreased dynamic friction with the fine-textured soils. Increases in soil moisture increased friction in all soils. The fine-textured soils had greater traction than the sandy soils, but no consistent calcined clay or moisture effects on traction were observed. Shear strength of the soils was highly correlated with traction and friction. The results suggest that differences in skinned infield soils are quantifiable, which could lead to the development of playing surface standards.

Abbreviations

CC, calcined clay; Ksat, saturated hydraulic conductivity.

Keywords

bulk density, dynamic friction, saturated hydraulic conductivity, shear strength, static friction, surface hardness.

INTRODUCTION

The skinned portions of baseball and softball infields are the non-grassed, bare-soil areas between the bases. They vary widely with respect to soil texture, applied amendments and conditioners, and soil water management. These variations influence soil physical properties, which can affect the playability (hardness, traction, friction) of the surface. Generally, recommendations for construction materials and maintenance practices for these surfaces have not been based on extensive research, but rather on the sports turf manager's preferences and experience, or marketing efforts that promote particular amendments or products. Few guidelines have been published for the construction of skinned infields (American Society for Testing and Materials, 2001; Waddington et al., 1997).

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Information regarding ball response off surfaces in the United States has been related primarily to golf and soccer surfaces (Brede, 1990; Dest and Guillard, 1999; Dest and Guillard, 2002; Weber, 1997). The closest similarity to ball response off baseball or softball skinned infields, for which data exist, is with cricket pitches located outside the United States. Balls used in cricket and baseball are similar in weight, diameter, and in the speed at which they rebound off the surface. Therefore, it seemed reasonable to us that the same soil physical properties that affect ball response off cricket pitches may be responsible for similar responses of baseballs off infield surfaces.

Stewart and Adams (1968) found that the playing characteristics of a cricket pitch were primarily a function of the top 25 mm of the soil. In the United Kingdom, surface hardness, ball rebound, and ball pace increased with greater bulk density and decreased with moisture content (Baker et al. 1998, 2001). Therefore, a small variability in soil moisture or bulk density, especially closer to the surface, may have the potential to change the overall surface playability, such as: ball rebound, ball pace, and surface hardness of the pitch (Stewart and Adams, 1968; Baker et al., 1998, 2001).

In addition to soil moisture affecting ball response, ball-to-surface friction can affect playability. Friction between the ball and the surface of cricket pitches has been reported to affect ball direction, rate of rotation of a spinning ball after contact with the surface, topspin of a ball, and overall ball speed (Bell et al., 1985). Baker et al. (1998) determined that moisture increased ball-to-surface friction and that the finest and most cohesive soil required the highest ball rotational force to move a ball in contact with the soil.

Routinely, player traction has been measured for sports shoes that have studs, cleats, or spikes to provide extra grip (Bell et al., 1985). Studded disc apparatuses, with a surface contact similar to an athletic shoe, are used to measure the torque necessary to shear the soil surface, which represents the act of the soil giving way underfoot of a player (Bell et al., 1985). The torque measurement permits the estimation of the soil's shear strength, which indicates the amount of traction obtained from the studded apparatus (Canaway, 1975). The amount of traction on a given surface aids in the determination of an acceptable playing surface. Traction is recognized as an important characteristic for sports turf, and standards have been proposed specifying their limits for a sports field (Canaway et al., 1990).

Proper moisture levels of skinned infields requires sports field managers to adapt infield water management according to soil particle size, particle configuration, and amount of soil and type of amendments. Soil amendments and the soil particle size affect the saturated hydraulic conductivity (Ksat) of soils (Brady and Weil, 2002). Waddington et al. (1974) found that additions of coarse amendments do not increase hydraulic conductivity rates until they reach a threshold level, which causes bridging of the coarse particles to occur and, as a result, increases the soil conductivity rate. McCoy and Stehouwer (1998) determined that amendment uniformity and particle size contribute to Ksat and bulk soil water retention for root zone mixes.

Based on research performed on similar sport surfaces and experiences of sports field managers, it is logical to assume that a combination of maintenance practices and varying soil composition, amendments, and moisture will affect ball response and surface properties on skinned infields. It is essential that these factors be considered with regards to playability and safety of skinned infields. The lack of published data on ball response and traction of skinned infields provided the motivation for this research project.

The objectives of this study were to determine (i) surface hardness, traction, and static and dynamic friction from skinned infield surfaces of different soil composition and moisture levels amended with varying rates of calcined clay (CC), and (ii) the effects of soil composition with varying CC rates on bulk density, Ksat, and shear strength.

MATERIALS AND METHODS

Skinned infield plots were constructed at the University of Connecticut's Plant Science Research and Teaching Farm in Storrs, Connecticut, USA in the summer of 2001. The plots consisted of five different soils of varying textural class, organic matter concentration, and sand fraction distribution (Table 1), and amended with four rates (0, 4.9, 9.8, and 19.6 kg m^{-2}) of CC (Turface Pro League; Profile Products LLC, Buffalo Grove, Illinois, USA). The added CC represented half, full, and double the recommended rate by the manufacturer. The soils were obtained from five northeast USA soil distributors. These particular soils and CC are used widely in baseball and softball infields in our region on both low- and high-end fields. The soil classified as a loamy coarse sand is actually a crushed rock product manufactured primarily for skinned infields. Even though a clay fraction was determined for this material based on particle size analysis,

Table 1. Percentages of soil separates, sand fraction distribution, and organic matter (OM) content of the five soils, calcined clay, and sublayer sand used to construct skinned infields, Storrs, Connecticut, USA.

				Sand fraction distribution							
				Sieve opening							
Soil	Sand	Silt	Clay	2mm	1mm	500μm	250μm	149μm	105μm	53μm	OM
		%				% retained by weight					g kg^{-1}
Silt loam	44.2	48.8	7.0	0	1.6	4.5	8.2	9.6	9.3	11.0	1.9
Loam	48.3	42.6	9.1	0	4.7	8.2	12.0	9.0	5.5	8.3	3.4
Coarse sandy loam	80.5	4.4	15.1	0	9.6	19.7	34.2	12.1	2.5	2.5	5.1
Loamy sand	77.2	17.1	5.7	0	2.6	7.1	22.9	18.8	12.0	13.8	1.1
Loamy coarse sand	84.3	3.1	12.6	0	27.2	21.2	15.0	8.2	5.7	6.8	0.1
Calcined clay	100	0	0	5.3	35.4	37.2	20.2	1.7	0.2	0	
Sublayer sand	99.9	<0.1	<0.1	0	6.4	22.1	42.3	22.1	5.6	1.4	

it does not possess clay mineralogy properties. The experiment was set out in a split-plot design with three replicates. Main plot treatments were the different soils and were arranged in a randomized complete block. Subplot treatments were the CC rates.

The plots were constructed following typical skinned infield construction methods. The site was located on a sod-covered, 1.0% north-facing slope. The sod was removed and the site was then delineated into fifteen 2 x 2 m main plots, each consisting of four 1 x 1 m subplots, with wooden dividers between subplots and a 70-mm turfgrass buffer between each main plot. Each plot was hand dug to a depth of 200 mm. All plots were filled with a sublayer of coarse sand (Table 1) to 100 mm, leveled, and compacted with a vibratory plate compactor in preparation for the surface layer of soil and CC mix.

The constructed infield soils were prepared offsite by tumbling pre-determined ratios of CC and the respective soil (kg kg^{-1}) in a cement mixer which provided a homogeneous mixed material. All mixes were installed to a depth of 100 mm in their respective plots, which followed the CC manufacturer's recommendation for new infield construction. After installation of the mix, each plot was compacted with a vibratory plate compactor.

In the summer of 2001, the soils were regularly raked, groomed, watered, and compacted. Beginning 1 Sept. 2001, the plots were subjected to a dry-down period and covered with plastic tarps when needed to exclude moisture. After adequate drying, soil water content of each subplot was determined from the weight loss of 54 mm diameter by 60 mm length cores after drying for 24 hours at 105°C, and was expressed as a percentage of both the dry unit weight of soil and the core volume. After dry down, soil water content in all plots was adjusted to 10% moisture (m^3 m^{-3}). Beginning in October 2001, measurements for surface hardness, traction, and static and dynamic ball-to-surface friction were taken at 10% moisture content then repeated at 14 and 18% moisture contents (m^3 m^{-3}) after the appropriate amounts of water were added to each plot. Experience led us to believe that at moisture levels higher than 18%, the soil surface would become unacceptable for game conditions. All watering preceded data collection by 24 hours to provide adequate water infiltration through the soil profile. Except for the period of actual data collection, plots were covered with plastic tarps to maintain the desired water content. Before data collection, the plots were maintained to simulate a game day condition that included a very light raking to loosen the top 20 mm of infield mix. The mean of four subplot measurements was used to represent the value for surface hardness, traction, and static and dynamic friction. Balls used were National Collegiate Athletic Association (NCAA) regulation baseballs.

Surface hardness was tested by a Clegg Soil Impact Tester with a missile weight of 2.25 kg and a drop height of 300 mm (Clegg, 1976). Surface traction was measured by using a friction/traction apparatus (Canaway and Bell, 1986) modified with steel baseball cleats. The disc of the apparatus had a three-cleat pattern consisting of the front portion of a standard NCAA regulation baseball cleat. Measurements were taken after the apparatus was weighted with 34 kg and dropped from a height of 152 mm. Canaway and Bell (1986) used a weight of 47.8 kg for this apparatus. Their weight was considered too heavy for use on bare-ground skinned infields, therefore, the lighter weight was considered more appropriate. The force required to initiate movement of the weighted cleats was measured with a torque wrench (N m).

Static ball-to-surface friction was measured by a modification of a studded disc apparatus used for measuring friction/traction (Canaway and Bell, 1986). The modification consisted of replacing the studded disc with two plates that held four baseballs. The lower plate had four openings with a slightly smaller diameter than the balls so that the baseballs protruded below the plate making contact with the surface. The balls were positioned so the seams were in contact with the soil when the apparatus was placed onto the surface and weighted with 34 kg. To avoid wear on the seam of the ball, all balls were repositioned to expose new seams for each experimental block. The force required to initiate rotational movement of the weighted plate with the balls on the surface was measured with a torque wrench (N m).

Dynamic ball-to-surface friction was measured using a pendulum apparatus (Baker et al., 1998) into which a ball was mounted to the end of the pendulum, so that the ball's leather surface, and not the seam, would contact the soil surface. The length of the pendulum to be used for each subplot was determined by positioning the pendulum perpendicular to the surface and lowering it until the ball made contact with the subplot's surface. The apparatus was then raised slightly to one side so that the pendulum could be pulled from the center of the apparatus without touching the surface. The raised apparatus side was then lowered back to the surface and the pendulum was elevated to an angle of 70° from the surface and released. To avoid wear on the ball, the ball was repositioned to a fresh leather surface for each experimental block. The angle reached after the ball made contact with the surface was recorded. A dynamic friction index value was then calculated by dividing the angle reached after the baseball contacted the surface by 70° (the maximum angle that could be achieved in the absence of any friction) then subtracting this quotient from 1. An index value of 0 indicated no frictional loss of the swing; a value of 1 indicated that the ball came to a complete perpendicular stop after it contacted the surface.

Two undisturbed core samples were removed from each subplot to determine Ksat and bulk density. Ksat was measured using a constant head permeameter while adjusting all results to a common temperature of 20°C (American Society for Testing and Materials, 1999a). Bulk density of each sample was determined from the oven dry weight and soil volume after oven-drying overnight at 105°C (Blake, 1965).

Samples were collected from the non-amended stock soils and the CC to determine particle size and organic matter (Table 1). After removal of the sand fraction, silt and clay content was measured using the pipette method (American Society for Testing and Materials, 1999b). The sand fraction was separated into class sizes of 2 mm, 1 mm, 500 μm, 250 μm, 149 μm, 105 μm, and 53μm by dry sieving (American Society for Testing and Materials, 1999b) and reported as the percentage retention by weight. The organic matter concentration was measured by loss on ignition at 400°C for 8 hrs and expressed as a percentage of the oven dry weight of soil.

In the laboratory, samples of the stock soils were amended with the CC to determine the optimum moisture content for packing, unconfined compressive strength, and shear strength of each soil–CC rate combination. Compaction characteristics for each soil–CC rate combination were determined by the Harvard miniature procedure (United States Department of the Interior, Bureau of Reclamation, 1989a) and unconfined compression test (United States Department of the Interior, Bureau of Reclamation, 1989b). Five total samples of each soil were compacted at different moisture contents to establish soil moisture–unit weight compaction curves. Each sample's moisture contents was regressed on its axial strain at point of failure to obtain a quadratic curve, from which an optimum moisture content for each soil–CC rate combination was calculated (Das, 1998). The procedure was repeated, except that the samples compacted at optimum moisture content were air dried before axial loading.

Treatment effects on bulk density, Ksat, shear strength, surface hardness, traction, and ball-to-surface static and dynamic friction were determined by analysis of variance (AOV). For the field data, soil water content was treated as a repeated measure. The levels of data for the repeated measures analysis were blocks/plots/repeated measures, with blocks and blocks x soil treated as random effects. A square root transformation for Ksat, a $\log_{10}$ transformation for shear strength, a reciprocal transformation for static friction, and a $\log_{10}$ transformation for dynamic friction were needed to normalize the data before AOV. Appropriate transformations were determined by a Box-Cox power transformation procedure (Box et al., 1978). Transformed means were converted back to original scale for data presentation. When significant, soil main effect differences were separated using Fisher's Least Significant Different test (α = 0.05). Single-degree-of-freedom orthogonal polynomial contrasts were conducted to determine the trend response effects of CC rates (linear, quadratic, or cubic) and soil moisture contents (linear and quadratic) for each soil when the Soil x CC or Soil x Moisture interactions were significant; otherwise the main effects of CC or moisture are presented and subjected to the same trend analysis procedures. The SAS procedure MIXED was used for AOV and the CORR procedure was used for correlation analyses (SAS Inst., 1999).

Table 2. Significant source effects from analysis of variance for skinned infield study, Storrs, Connecticut, USA.

Variable	Bulk density	Ksat	Shear	
			Dry	Moist
Soil (S)	*	**	**	**
Calcined clay (CC)	**	*	**	**
S x CC	NS	NS	**	**

Variable	Hardness	Traction	Friction	
			Static	Dynamic
S	NS	**	**	**
CC	**	NS	**	*
Moisture (M)	**	**	**	**
S x CC	*	NS	NS	*
S x M	**	*	**	**
CC x M	NS	NS	NS	NS
S x CC x M	NS	NS	NS	NS

*, **, NS = P<0.05, P<0.01, and not significant (P>0.05), respectively.

RESULTS AND DISCUSSION

Bulk Density

Across all soils, bulk density decreased linearly as CC rates increased (Tables 2, 3). This was attributed to the low density of the CC amendment (0.54 Mg m^{-3}). Similarly, Waddington et al. (1974) observed decreases in bulk density when incorporating a similar CC amendment into silt loam turfgrass plots. In situations where skinned infields would benefit from decreased bulk density (i.e., compacted conditions), the incorporation of CC into infield soils would probably achieve this goal.

Saturated Hydraulic Conductivity

The sandy soils had significantly greater Ksat rates than the finer-textured soils (Tables 2, 3). Overall, an increase in CC rate significantly increased the Ksat of the infield soils, and it followed a linear trend (Table 3). Bridging of sand particles and the CC probably provided connecting pores, thereby resulting in greater Ksat as CC rates increased.

Our results agree with previous observations by Waddington et al. (1974), who noted that the addition of coarse and/or low-density amendments, such as CC, increased soil permeability once a threshold had been reached, resulting in the bridging of the coarse particles.

Table 3. Mean bulk density, saturated hydraulic conductivity (Ksat), dry shear strength, and moist shear strength for five soils amended with four rates of calcined clay (CC) used for the construction of skinned infields Storrs, Connecticut, USA. Significant interaction effects are indicated by the display of individual soil responses across CC rates. In the absence of a significant interaction, only main effect means are presented.

Soil	Bulk density	Ksat	Dry shear strength					Moist shear strength				
	Mg m^{-3}	mm hr^{-1}			kPa					kPa		
Silt loam (sil)	1.70 a†	14.7 c			552a					37.0a		
Loam (l)	1.57 b	7.7 c			215b					34.4a		
Coarse sandy loam (csl)	1.66 a	37.0 b			137c					22.7b		
Loamy sand (ls)	1.64 a	26.7 b			128c					4.4c		
Loamy coarse sand (lcs)	1.64 ab	67.3 a			32d					5.0c		
CC rate			sil	l	csl	ls	lcs	sil	l	csl	ls	lcs
- kg m^{-2} -												
0.0	1.72	23.5	540	419	184	136	25.5	38.8	47.7	29.2	10.1	11.1
4.9	1.67	22.2	587	225	149	145	26.3	45.8	39.4	29.0	3.6	5.9
9.8	1.63	29.8	686	164	145	143	47.5	36.7	32.6	21.2	4.4	3.3
19.6	1.54	34.4	428	139	89	94	33.4	28.7	22.7	14.7	2.4	3.0
Linear	**	*	NS	*	**	NS	**	**	**	**	**	**
Quad.	NS	NS	*	NS	NS	*	*	NS	*	NS	**	NS
Cubic	NS	NS	NS	NS	NS	*	NS	NS	**	NS	NS	NS

† Means within a column for soils followed by the same letter are not significantly different, $P<0.05$.

*,**,NS = $P<0.05$, $P<0.01$, and not significant ($P>0.05$), respectively.

Also, Waddington (1992) reported that internal porous inorganic amendments, such as CC, increased the Ksat an average of twice the rate for coarse-textured soils compared to fine-textured soils. Therefore, CC can affect the Ksat of soils when the soil particles and the CC particles are satisfactory to enable soil particle bridging within the soil profile.

Shear Strength

Soils compacted at their optimum moisture content and then exposed to axial strain at both dry and moist conditions, generally decreased in shear strength with increasing CC rates (Tables 2, 3). Dry shear strength values were a magnitude or more greater than the moist soils. This difference in shear strength between moist and dry conditions corresponds with numerous studies. Douglas (1986) noted significant differences in shear strength between wet and dry soils when measuring strength in clay topsoil. Furthermore, Rogers et al. (1988) reported that shear resistance is usually greater on dry soils.

Soils with a greater coarse fraction exhibited less shear strength than the finer-textured soils (Table 3). Overall, the silt loam, at dry and moist conditions, exhibited the greatest strength and least amount of weakening with the addition of CC, which is attributed to the silt loam's particle cohesiveness. Fine-textured soils are more susceptible to direct particle-to-particle contact, which is directly responsible for higher shear strengths (McNabb and Boersma, 1993). High amounts of silt and clay proportions in soil, makes it less likely for dilution of the soil with sand sized particles (Whitmeyer and Blake, 1989), such as calcined clay. For those reasons, finer-textured soils are more likely to have greater shear strength than coarser soils due to their cohesiveness.

In addition to preserving strength, silt and clay fractions can contribute significantly to the physical characteristics of soils with high sand contents, especially when in excess of 80% (Whitmeyer and Blake, 1989). More importantly, shear strength is strongly dependant upon clay properties and content (Whitmeyer and Blake, 1989). This may explain the differences we observed in shear strength between the coarse sandy loam, loamy sand, and the coarse loamy sand, which were all in excess of 77% sand. Out of these soils, the coarse sandy loam exhibited the least relative loss in moist shear strength with the addition of CC (Table 3), which was probably due to its larger amount of clay (Table 1). Accordingly, coarse-sandy soils may exhibit greater shear strengths when their clay fraction is significantly greater in proportion to the silt fraction.

Surface Hardness

Across soils, mean surface hardness values ranged from 88 to 111 Gmax (Table 4). These values match the hardness readings for baseball skinned infields in our region (Dest, unpublished data). For comparative purposes, a concrete floor produced a value of 1280 Gmax and declined to 260 Gmax after the same floor was covered with a carpet pad, whereas hardness of 24 Pennsylvania, USA athletic fields ranged from 33 to 167 Gmax (Rogers et al., 1998). Surface hardness of the soils responded differently across CC rates; the addition of CC significantly increased the surface hardness of the loam, loamy sand, and loamy coarse sand soils (Tables 2, 4), but not the silt loam or the coarse sandy loam.

Moisture content was the primary influence on surface hardness, which corresponds to previous research (Baker, 1989; Baker, 1991; Rogers and Waddington, 1992). Surface hardness decreased in all soils as the moisture increased, with the greatest decreases occurring in the

Table 4. Mean surface hardness, surface traction, static ball-to-surface friction, and dynamic ball-to-surface friction for five soils used for the construction of skinned infields Storrs, Connecticut, USA, across varying rates of calcined clay (CC) and soil moisture levels. Significant interaction effects are indicated by the display of individual soil responses across CC rates and/or moisture levels. In the absence of a significant interaction, only main effect means are presented.

Soil	Surface hardness					Traction					Static friction					Dynamic friction				
	Gmax					Nm					Nm					Index‡				
Silt loam (sil)	88a†					29.2 a					44.7 a					0.59 a				
Loam (l)	102a					28.6 a					38.4 b					0.50 ab				
Coarse sandy loam (csl)	104a					26.4 b					37.0 b					0.42 b				
Loamy sand (ls)	110a					22.8 c					33.7 c					0.32 c				
Loamy coarse sand (lcs)	111a					24.5 bc					33.6 c					0.33 c				
CC rate	sil	l	csl	ls	lcs											sil	l	csl	ls	lcs
- kg m^{-2} -																				
0	85	91	99	97	111	26.4					38.4					0.68	0.58	0.42	0.30	0.32
4.9	89	105	107	99	110	26.3					37.8					0.63	0.49	0.41	0.38	0.29
9.8	87	105	103	117	104	26.2					36.9					0.55	0.50	0.41	0.34	0.38
19.6	89	106	104	125	121	26.2					36.0					0.49	0.44	0.44	0.27	0.32
Linear	NS	*	NS	**	NS	NS					**					**	*	NS	NS	NS
Quad.	NS	NS	NS	NS	*	NS					NS					NS	NS	NS	NS	NS
Cubic	NS	NS	NS	NS	NS	NS					NS					NS	NS	NS	NS	*
Moisture	sil	l	csl	ls	lcs	sil	l	csl	ls	lcs	sil	l	csl	ls	lcs	sil	l	csl	ls	lcs
- % -																				
10	104	111	109	113	112	29.3	29.3	26.3	23.1	25.8	43.6	36.6	35.9	30.8	32.1	0.34	0.28	0.39	0.20	0.21
14	92	107	101	115	116	28.8	28.1	25.5	23.0	23.3	42.4	37.8	39.2	35.1	34.4	0.53	0.50	0.45	0.35	0.34
18	67	87	100	101	106	29.4	28.3	27.4	22.2	24.5	48.5	41.1	39.0	35.7	34.3	0.84	0.67	0.41	0.37	0.39
Linear	**	**	*	**	NS	NS	NS	NS	NS	*	**	**	**	**	**	**	**	NS	**	**
Quad.	NS	*	NS	*	*	NS	NS	*	NS	**	**	NS	*	**	*	NS	NS	NS	*	NS

† Means within a column for soils followed by the same letter are not significantly different, $P<0.05$.

‡ Index 0 = no friction; 1 = complete stop after contacting surface.

*,**,NS = $P<0.05$, $P<0.01$, and not significant ($P>0.05$), respectively.

finer-textured soils (Tables 2, 4). Similarly, Baker (1989) observed that finer-textured soils exhibit greater decreases in hardness when wet, than wet coarser-textured soils. In contrast, the well packed, coarser soils in our study (coarse sandy loam, loamy sand, and loamy coarse sand) had fewer surface hardness differences with respect to increasing soil moisture content, probably due to their ability to drain more freely (Baker, 1989; Bell and Holmes, 1988).

Surface hardness differences are to be expected due to texture, moisture and compaction levels, because of their strong interdependence with each other, whereas increased soil water content has the potential to mask the effects of bulk density (i.e. compaction) (Rogers and Waddington, 1992). Therefore, moisture is probably the main variable that affects surface hardness in skinned infield soils, but the extent to which surface hardness is affected is dependant upon particle shape and size, clay/silt contents, and compaction levels.

Surface Traction

Traction was greater for the silt loam and loam soils compared with the sandy soils (Tables 2, 4). There were no CC rate effects on traction. Traction responded differently for soils across moisture levels, but no clear or meaningful trends were apparent (Table 4). Although few effects were found, it could be assumed that moisture would have a significant effect once a certain threshold moisture level is reached, which was probably higher than the moisture levels we tested in the field. Similarly, Baker (1991) reported little variation in traction associated with moisture content.

Traction studies performed on turfgrass plots (Baker, 1989, 1991; Canaway, 1975, 1981) resulted in substantially higher traction values than the skinned infield plots. These differences between turf surfaces and skinned infield surface are most likely attributable to the plant root system increasing the soil's tensile strength (McAuliffe and Hannan, 2001). However, studies that included data from tests completed on bare ground were comparable to data reported herein (Canaway, 1981).

Static Ball-to-Surface Friction

Static ball-to-surface friction increased as soils became finer in texture and decreased with increasing CC rates (Tables 2, 4). Moisture increased static friction for all soils, but at different rates (Table 4). Likewise, Baker et al. (1998) reported friction measurements to be at their highest in the wettest month of the year, and that the finest-textured soil had the highest frictional resistance when using a similar measuring device for cricket pitches.

The silt loam required the greatest rotational force to initiate movement of the baseballs, which was probably attributable to the greater shear strength in this soil compared with the other soils (Table 3). Our data corresponds with previous studies from Baker et al. (1998) and Adams and Young (2001). High static friction produced by the finer-textured soils may be also influenced by their

Table 5. Correlations between mean shear strength and mean traction, static friction, and dynamic friction at varying soil moisture contents for the soil-CC rate combinations (n=20).

	Shear strength	
	Dry	Moist
	r value	
	10 % soil moisture	
Traction	0.62**	0.82**
Static friction	0.87**	0.85**
Dynamic friction	0.36 ns	0.56*
	14 % soil moisture	
Traction	0.77**	0.91**
Static friction	0.85**	0.80**
Dynamic friction	0.68**	0.79**
	18 % soil moisture	
Traction	0.67**	0.87**
Static friction	0.87**	0.94**
Dynamic friction	0.83**	0.90**

*, **, ns = $P<0.05$, $P<0.01$, and not significant ($P>0.05$), respectively.

susceptibility to surface deformation, which may increase even more with additional moisture (Baker et al., 1998). However, particle size and the area of contact between the ball and the soil surface are the most relevant soil properties for the determination of ball-to-surface friction (Adams and Young, 2001).

Dynamic Ball-to-Surface Friction

Generally, observed results for dynamic friction were similar to those of static ball-to-surface friction, with the finer-textured soils (silt loam and loam) exerting greater frictional resistance than the coarser-textured soils (coarse sandy loam, loamy sand, and loamy coarse sand) across CC rates (Tables 2, 4). Also, dynamic friction significantly increased with increased moisture (Table 4).

Dynamic ball-to-surface friction has application for skinned infields in situations where ball rebound velocity off the surface is perceived to be a function of an unacceptably hard surface, when in fact, it may be due to a low friction coefficient of that surface. Dest (unpublished data) used the same pendulum device to distinguish differences on baseball skinned infields where Gmax values were actually lower for surfaces with a higher ball rebound velocity off the surface compared with skinned infields that had a lower ball rebound velocity. This suggested that surface hardness per se, was not resulting in the higher velocity off the surface. The pendulum device, however, was able to show that the dynamic ball-to-surface friction was significantly lower on the skinned infield with the higher ball rebound velocity. Therefore, the reduced friction resulted in less slowing of the ball velocity as it left the surface. This suggests that the frictional properties of certain surfaces may be more important than surface hardness with respect to ball rebound velocity. Similarly, Adams and Young (2001) observed frictional differences between soil particles of prepared surfaces and the surface of the ball. Differences in friction were attributed to soil particle-to-ball surface contact and particle shape.

Our results suggest also that the decision to add CC to fine-textured soils should be made with consideration of potential changes in surface friction. If the objective were to slow the velocity of the ball off the surface, then CC application rates should be limited on fine-textured soils. Addition of CC would only serve to reduce surface friction and not achieve the goal. On the other hand, if ball velocity off the surface of fine-textured soils is deemed unacceptably slow, then additions of CC would help to reduce the surface friction leading to a faster ball rebound velocity.

Correlations

The use of a shear strength test provides a method for predicting how infield soils may perform in the field as shown by the relationship between shear strengths and playability characteristics of the surface properties (Table 5). Surface traction was positively correlated with shear strength, and the relationship was strongest at 14% moisture. Shear strength and frictional properties were positively correlated, and the relationship was stronger as moisture levels increased. These relationships suggest that easily available and affordable shear strength tests (e.g., shear vane apparatus, or soil laboratories that conduct strength analyses) could be used to predict surface playability characteristics, which require more sophisticated or specialized equipment to determine.

CONCLUSIONS

The results of this study suggest that the playability of baseball and softball skinned infields is affected by the CC rate, soil composition, and moisture content. In general, the fine-textured soils responded differently than the coarse-textured soils for most variables. Differences within textural classes were observed, and probably attributable to differences in particle shapes, sand fraction distribution, and clay content. The effects of CC are probably attributable to the potential modification of the textural class of a finer-textured infield skinned soil to one of a coarser-textural class. Therefore, addition of CC to fine-textured soils may cause them to react similarly to coarser-textured soils.

Most importantly, the results from this study indicate that differences in skinned infield soils are quantifiable. This raises the possibility that playing surface standards might be developed for skinned infields using the techniques presented in this study. More research is needed, however, before reaching that endpoint. This would include quantifying infields with respect to hardness, traction, friction, shear strength, etc., and matching those values to player preferences and acceptability.

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