

## Surface hardness in relation to slope on cricket pitches in the Caribbean

Louis E. Chinnery and Francis B. Lopez

*Sports Agronomy Research Unit, Department of Biological and Chemical Sciences, The University of the West Indies, Cave Hill Campus, BB11000, Barbados*

*[louis.chinnery@cavehill.uwi.edu](mailto:louis.chinnery@cavehill.uwi.edu)*

### ABSTRACT

The Clegg Hammer has been shown to be a useful instrument for determination of surface hardness characteristics of cricket pitches. However, it has been suggested that errors may occur if the instrument is not held vertically upright during measurements due to friction between the falling hammer and the barrel of the instrument, as well as variation in the angle of impact of the flat hammer on the surface. Prepared cricket pitches are usually not perfectly flat and some slope is often desirable to facilitate surface water drainage. Tests were conducted on pitches that were selected for use during the ICC Cricket World Cup in 2007 with the aim of determining whether surface hardness as measured with the Clegg Hammer is related to the size or direction (east-west vs. north-south) of the slope on the cricket pitches. Pitches were prepared as required for a match and surface hardness and slope measurements were made at 20 locations on each pitch. The Clegg Hammer instrument was placed squarely on the surface for all measurements so that the orientation of the instrument to the vertical depended on the surface slope at each location. It was assumed that the angle between the surface of the falling hammer and that of the cricket pitch immediately below is zero. The surface slope was less than 2% at all locations with a wide range of slope directions for all pitches sampled. There was a trend for positive

correlations between Clegg readings and pitch slope suggesting that errors due to frictional forces between the falling hammer and the barrel of the instrument are not likely to be paramount. Cricket pitches with a mean slope in the north-south direction tended to have higher Clegg readings, and were apparently more variable with regard to slope direction and size of the slope compared to those with mean slope in the east-west direction. The surface hardness of cricket pitches as determined by the Clegg Hammer can be affected by the orientation of the surface at the point of measurement.

## **INTRODUCTION**

The pace of a cricket pitch can be defined as the degree to which ball speed is maintained following impact, and a fast-pace pitch is generally considered to be desirable (James, 2004). An indication of the pace of a cricket pitch can be obtained by measuring the rebound speed (or height) of a cricket ball dropped from a standard height (Stewart and Adams, 1968), and measurements are often facilitated by use of a high-speed video camera. The development of the Clegg Impact Hammer (Lush, 1985) as a portable instrument for surface hardness determinations has provided an alternative method for assessing the pace of cricket pitches using a less cumbersome procedure. The instrument measures the rate of deceleration of a hammer dropped from a standard height, and the mass of the hammer varies in different models. Clegg Hammer readings have been found to relate well to the rebound height of a ball dropped from a standard height above the surface (Baker et al., 2001), and the 2.25 kg model has been shown to be very useful on cricket pitches (McAuliffe and Hannan, 2001). The instrument is designed to be used on flat surfaces and vertical orientation of the instrument is recommended during measurements. Cricket pitches are relatively very flat and well suited for measurements with the Clegg Hammer.

Some performance standards for cricket fields are provided in the official cricket rules (Marylebone Cricket Club, 2003) and details of recommended maintenance practices are also available (Adams and Gibbs, 1994, Evans, 1996, McIntyre and McIntyre, 2001, Tainton and Klug, 2002). A cricket field can have one or more clay pitches oriented parallel to each other to form the cricket square or wicket table, which is centrally located within the generally more well-drained soil of the outfield. Grass on a pitch is cut low during pitch

preparation and the clay is compacted by cycles of watering and rolling. It is generally recommended that the slope on cricket pitches should not exceed 1% in any direction (McIntyre and McIntyre, 2001, Tainton and Klug, 2002). However, it is not expected that the pitch should be perfectly level (horizontal), and a small designed, directional slope is beneficial to facilitate run off of surface water which can otherwise lead to the development of wet spots. It is possible that moisture gradients across the pitch may impart directional properties to surface hardness as measured with the Clegg Hammer at non-vertical instrument orientations. Pitch operations such as mowing, verticutting and rolling are often done predominantly in the north-south direction along the length of the pitch. It is conceivable that such operations can also lead to directional structural features that may influence measurements made with the Clegg Hammer when the orientation of the instrument is non-vertical.

Possible errors in measurements with the Clegg Hammer include frictional forces between the hammer and the barrel of the instrument, a build-up of air pressure below the falling hammer, and an inconsistent angle of contact of the flat hammer with the surface (Carre et al., 2006). Therefore, the orientation of the instrument relative to the surface and the vertical during measurements may be critical for consistent readings. Suggested instrument modifications to reduce inconsistencies include a hemispherical hammer and the use of a rail system to provide a more controlled drop of the hammer to the surface (Carre et al., 2006). The initial contact of the leading edge of a flat hammer falling to the surface can lead to twisting moments on the hammer that increase instrument vibration and noise levels. In the following study, we investigate whether surface hardness measured with the Clegg Hammer is related to the size or direction (east-west vs. north-south) of the slope on eight cricket pitches across the Caribbean region, which were selected for use during the International Cricket Council's (ICC) Cricket World Cup 2007.

## **METHODS**

Cricket pitches located on six cricket fields in the Caribbean Region (Table 1) were prepared as required for a match and pitch characteristics were determined based on observations at 20 sampling locations (McAuliffe and Gibbs, 1993) with measurements of slope and surface hardness done at each location. A measurement tape was first placed

along the center of the pitch from middle stump to middle stump. Ten observations were made at 2m intervals along the western side starting 1m from the line of the stumps at the northern end and 0.5m from the center line, and ten corresponding observations were made along the eastern side of the pitch (Fig. 1). Pitch slope at each location was determined in the east-west and north-south directions using a 60-cm-long digital leveling tool (M-D Building Products, USA), which indicated the slope in degrees and the direction for movement of the leveling tool towards the horizontal. The true slope and slope direction were then calculated from these measurements.

The measured slopes were assigned positive or negative values depending on the direction of the slope towards the horizontal. True pitch slope ( $S$ ) at each location was determined as the resultant of the slope in two directions ( $S_1$ ,  $S_2$ ) at right angles to each other using the relationship:

$$S^2 = S_1^2 + S_2^2$$

The direction of the true slope was determined in degrees using the conventional system (North = 0°, East = 90°, South = 180° and West = 270°). The direction quadrant was first determined using the positive and negative signs assigned to values determined with the digital leveling tool. The direction of the slope within a particular quadrant was determined as an angle ( $\theta$ ) using the relationship:

$$\text{Sine } (\theta) = (S_1 \text{ or } S_2) / S$$

Either  $S_1$  or  $S_2$  was used in the calculations depending on which quadrant was involved. If the measured slopes in both directions were zero (which occurred very rarely), then a direction was assigned based on results in the immediate vicinity. The absolute value of the sine of the direction in degrees (absolute-sine-degrees) was calculated in order to carry out statistical analyses using slope direction. In this way, pitch slope direction was expressed as a number between 0 and 1, with 0 indicating the north-south direction and 1 indicating the east-west direction.

Pitch surface hardness was determined using a 2.25kg Clegg Hammer (Model 95049, Lafayette Instrument Company, USA). The hammer was dropped from a height of 45cm

and peak deceleration values were recorded by the instrument as Clegg readings in units of gravities (g) following four successive hits of the hammer on the same spot. The instrument was placed squarely on the surface for all measurements so that the orientation of the instrument to the vertical depended on the surface slope at each location. The angle between the surface of the falling hammer and that of the cricket pitch surface immediately below was assumed to be zero. The base of the instrument covered an area of approximately 10 x 15cm, and the cross-sectional diameter of the hammer was 5cm. Measurements with this instrument were terminated whenever there were obvious surface depressions created by the falling hammer, which sometimes occurred on incompletely prepared pitches.

In addition to the peak deceleration recorded with the Clegg Hammer, two surface constants were calculated based on the asymptotic relationship expected between Clegg Readings and the number of successive hits with the hammer on the same spot (Lopez and Chinnery, 2009):

1.  $C_{max}$  – ‘the predicted maximum Clegg reading if successive hits with the hammer continued indefinitely on the same spot’
2.  $K_C$  – ‘the theoretical number of hits with the hammer needed to produce a Clegg Reading equal to half of  $C_{max}$ ’

These surface constants allow us to predict Clegg readings in relation to the number of hits (H) with the hammer on the same spot using the relationship:

$$\text{Clegg reading} = (C_{max} \times H) / (K_C + H)$$

$K_C$  values in the range 0 to 0.45 have been reported (Lopez and Chinnery, 2009) and low values (below 0.15) are indicative of highly stable Clegg readings with successive hits with the hammer. Determinations were made within the period 4-6 months prior to the start of Cricket World Cup 2007 on selected cricket pitches across the Caribbean region with repeat visits to some pitches. Data were subjected to correlation analysis using the statistical software package PASW Statistics 18 (SPSS Inc., USA), and Pearson's correlation coefficient was determined for all analyses. Additionally, Spearman's

correlation coefficient was computed for analyses involving slope direction (expressed as absolute-sine-degrees), as this non-parametric method avoids assumptions about data distribution and homogeneity of variances for this derived variable. Pearson's correlation coefficients were selected for presentation where the results from both analyses were similar.

## RESULTS AND DISCUSSION

Surface hardness parameters and slope of cricket pitches were determined at various stages in all countries involved in Cricket World Cup 2007. Results are presented for 8 cricket pitches across the region where both Clegg readings and surface slope were determined at the same time (Table 2). For these pitches, average Clegg readings varied from 207g to 424g, and average pitch slopes (degrees) varied from 0.23 to 0.68. Mean surface hardness (Clegg) readings have been used to indicate pitches that were slow (below 200g), medium-fast (200-350g) or fast (over 350g) based on measurements with the 2.25kg Clegg instrument (Lopez and Chinnery, 2009). There was a weak positive correlation between Clegg reading and pitch slope, which became significant (Pearson's  $r = 0.805$ ,  $p = 0.029$ ) if data for CPK Jamaica were excluded from the analysis (Table 2). It is possible that the relationship between Clegg readings and pitch slope did not hold for CPK Jamaica due to the high variability of Clegg readings on this pitch. A positive correlation between Clegg reading and pitch slope is not expected if frictional forces between the falling hammer and the barrel of the instrument (Carre et al., 2006) is paramount. Such frictional forces should reduce the speed of the falling hammer and lead to a reduction in the peak deceleration as the hammer strikes the surface.

There was a strong positive correlation (Pearson's  $r = 0.907$ ,  $p < 0.01$ ) between the Clegg reading standard errors and  $K_c$  (Table 2), suggesting that error bars associated with the determination of mean pitch Clegg readings increase as  $K_c$  increases. A high  $K_c$  value is associated with surface fluidity that may be indicative of an inadequately prepared or a deteriorating surface (Lopez and Chinnery, 2009).

The extent of the surface slope was less than 2% at all individual locations on the pitches and mean values varied between 0.23 and 0.68 degrees (Table 2). A common

recommendation is that the slope on cricket pitches should not exceed 1% (0.6 degrees) in any direction (McIntyre and McIntyre, 2001, Tainton and Klug, 2002). A significant negative correlation (Pearson's  $r = -0.754$ ,  $p = 0.031$ ) was observed between mean slope direction (absolute-sine-degrees) and its standard error. Cricket pitches with a mean slope in the north-south direction were apparently more variable with regard to slope direction compared to those with mean slope in the east-west direction. There was also a significant negative correlation (Pearson's  $r = -0.726$ ,  $p = 0.042$ ) between mean slope direction (absolute-sine-degrees) and slope standard error, suggesting that pitches with a mean slope in the north-south direction were also more variable with regard to size of the slope.

The direction of slopes on the cricket pitches varied greatly, with the percentage area that sloped in specified directions varying from 0% to 75% (Table 3). The slope direction was predominantly east-west for one pitch (SAB Jamaica) and north-south for two pitches (KNO Barbados and UWI Trinidad). There were non-significant differences in the frequency of occurrence of east, west, north and south facing slopes for four out of the eight pitches sampled based on the chi-square test (Table 3). The slope direction (expressed as absolute-sine-degrees) was high for KNO Barbados and low for SAB Jamaica (Table 2) reflecting the predominant north-south and east-west slope orientations, respectively. The pitches with the lowest Clegg readings (KNO Barbados and UWI Trinidad) tended to have slopes predominantly in the east-west direction (Table 3).

With the exception of one pitch (BCG Guyana), there was a trend for positive correlations between Clegg readings and pitch slope based on measurements made at 20 sampling locations on each pitch (Table 4). Correlations were significant for two pitches (SAB Jamaica and UWI Trinidad) and appeared to become stronger for the correlation between  $C_{max}$  and slope on these pitches. These results reinforce the previously stated view that the frictional force between the falling hammer and the barrel of the instrument is unlikely to be a dominant factor for these measurements. Clegg readings were highly correlated with  $C_{max}$  values but standard errors tended to be higher for  $C_{max}$  (Table 2). Further investigations are needed to elucidate possible reasons for the observed higher correlation of pitch slope with  $C_{max}$  values compared to that with Clegg readings.

Repeat measurements on certain pitches indicated that pitch slope determined at a particular date may be related to Clegg readings determined at a subsequent date. This

was observed for the KNO Barbados pitch, where Clegg readings were significantly correlated (Pearson's  $r = 0.490$ ,  $p = 0.028$ ) with pitch slope determinations made one week previously. Interestingly, an even stronger correlation (Pearson's  $r = 0.537$ ,  $p = 0.015$ ) was observed between the corresponding Cmax and pitch slope determined one week earlier. These correlations were not significant when both Clegg readings and pitch slope were determined initially at the same time (Table 4). Such correlations were not observed with repeat measurements made for pitches at the Cave Hill Campus (3WS Barbados) and may be related to the different approaches that can be used to remove pitch undulations.

There was a consistent trend for negative correlations between the size of the slope and slope direction (expressed as absolute-sine-degrees) based on measurements made at 20 sampling locations on each pitch (Table 5). This negative correlation was significant for one pitch (CPK Jamaica), and the results suggest that the size of the slope was smaller for locations on the pitch that sloped more in the east-west direction. Such results may be expected if important pitch operations such as rolling and scarification are carried out predominantly in the north-south direction. Longitudinal undulations can be reduced by regular cross-rolling and diagonal-rolling (McIntyre and McIntyre, 2001). A significant negative correlation was observed between slope direction (expressed as absolute-sine-degrees) and Clegg reading for one pitch (3WS Barbados Pitch #3, Table 5). This finding is in agreement with the previously stated observation that surface hardness tends to be lower for slopes in the east-west direction. Pitches at the edges of the wicket square are often sloped predominantly in the east-west direction so as to facilitate excess water run-off towards the outfield. The spreading of pitch clay into the outfield soil and moisture uptake from the outfield can reduce the effectiveness of compaction operations, which can result in lower surface hardness of these pitches.

Significant amounts of moisture can be trapped in undulations due to slopes that are too flat (McIntyre and McIntyre, 2001) which can lead to the occurrence of wet spots with low surface hardness. Corresponding soil moisture tests were not done in this study, as surface disturbance by insertion of moisture probes was not allowed on pitches prepared for play. Pitch covers were available at all cricket fields so that precipitation was excluded from the pitches during preparation prior to testing. Grounds staff are expected to adjust their pitch preparation techniques, especially with regard to irrigation, depending on atmospheric evaporative demand. Pitch characteristics such as clay type and grass cover

are likely to vary at each site, which would affect the rate of pitch drying. Surface hardness was sufficiently high at all cricket sites and pitch locations sampled to prevent obvious indentations during measurements with the Clegg Hammer.

This study has provided information on the association between surface hardness properties and slope on cricket pitches in the Caribbean region. The observed significant positive correlation between surface hardness and pitch slope suggests that any errors due to a non-vertical orientation of the Clegg Hammer instrument during measurements is likely to be relatively small in comparison to the apparent effect of slope on measured surface hardness. Increased surface hardness due to reduced water retention by the pitch clay on greater slopes is a possible explanation for these results. It is also possible that a less vertical (more towards the horizontal) strike with the hammer may test a larger proportion of the hard surface layer compared to a vertical strike, which may be more likely to impact deeper less compacted layers. Surfaces that sloped in the north-south direction tended to have higher Clegg readings, but were more variable than those that sloped in the east-west direction. The carrying out of pitch operations predominantly in the longitudinal direction may offer a possible explanation for these results, and further work is needed to elucidate such mechanisms.

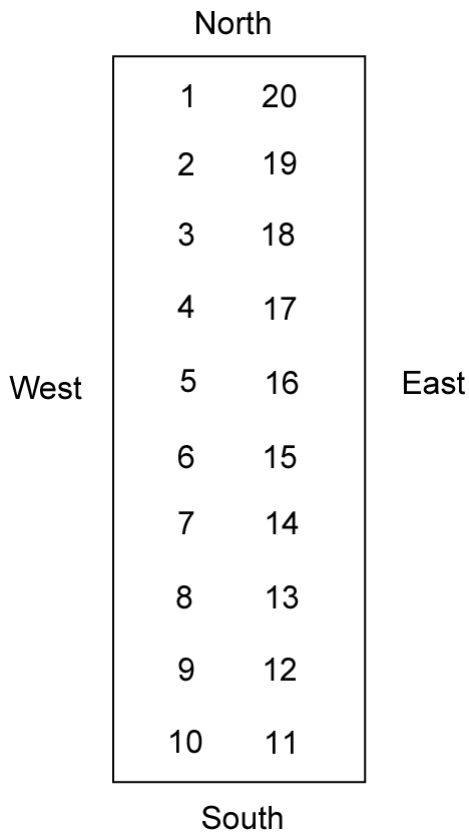
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**Figure 1. Sequence and sampling locations for Clegg Hammer and pitch slope measurements on cricket pitches. Observations along the 20m-long pitch were made at 2m intervals starting 1m from the line of the stumps at the northern end.**

**Table 1. Latitude-longitude location of cricket fields on which one or more pitches were tested. Coordinates were determined at the center of each field. Fields are arranged in order of increasing latitude.**

<b>Cricket Field</b>	<b>Location (Latitude-Longitude degree coordinates)</b>
BCG, Guyana	N6.80819 W58.14983
UWI, Trinidad	N10.63942 W61.39602
KNO, Barbados	N13.10511 W59.62251
3WS, Barbados	N13.135597 W59.63100
SAB, Jamaica	N17.97806 W76.78245
CPK, Jamaica	N17.98129 W77.00269

**Table 2. Mean values of Clegg readings (gravities), Cmax, Kc, slope (degrees) and slope direction (absolute-sine-degrees) for cricket pitches sampled across the region. Pitches are arranged in order of decreasing mean Clegg readings and standard errors are given in parenthesis.**

Cricket Pitch / Date	Clegg Reading	Cmax	Kc	Slope	Direction
3WS, Barbados, Pitch #2 6 Nov 2006	424 (12.1)	441 (13.0)	0.183 (0.0368)	0.68 (0.050)	0.66 (0.063)
CPK, Jamaica, Pitch #1 19 Nov 2006	390 (20.4)	426 (23.6)	0.364 (0.0462)	0.32 (0.049)	0.62 (0.070)
3WS, Barbados, Pitch #3 08 Nov 2006	284 (8.0)	292 (9.0)	0.098 (0.0300)	0.53 (0.068)	0.73 (0.059)
3WS, Barbados, Pitch #4 1 Nov 2006	270 (7.9)	277 (10.1)	0.099 (0.0351)	0.57 (0.070)	0.69 (0.052)
SAB, Jamaica, Pitch #4 19 Nov 2006	259 (8.0)	267 (8.3)	0.110 (0.0211)	0.56 (0.119)	0.38 (0.081)
BCG, Guyana, Pitch #2 30 Oct 2006	253 (8.1)	262 (8.6)	0.109 (0.0178)	0.36 (0.044)	0.57 (0.078)
KNO, Barbados, Pitch #3 19 Oct 2006	235 (10.0)	242 (11.7)	0.109 (0.0236)	0.32 (0.032)	0.75 (0.056)
UWI, Trinidad, Pitch #4 31 Oct 2006	207 (13.0)	224 (14.9)	0.331 (0.0691)	0.23 (0.030)	0.67 (0.078)

**Table 3. Percentage of area sloping in the directions of east (45-135°), west (225-315°), north (315-45°) and south (135-225°) for cricket pitches sampled across the region. Pitches are arranged in order of decreasing mean Clegg readings.**

Cricket Pitch	East	West	North	South	Chi-square
3WS, Barbados, Pitch #2	15	35	20	30	2.0 (p=0.57)
CPK, Jamaica, Pitch #1	35	15	10	40	5.2 (p=0.16)
3WS, Barbados, Pitch #3	35	25	25	15	1.6 (p=0.66)
3WS, Barbados, Pitch #4	45	0	30	25	8.4 (p=0.04)
SAB, Jamaica, Pitch #4	5	15	5	75	27.2 (p<0.01)
BCG, Guyana, Pitch #2	20	25	15	40	2.8 (p=0.42)
KNO, Barbados, Pitch #3	60	5	20	15	14.0 (p<0.01)
UWI, Trinidad, Pitch #4	60	10	15	15	13.2 (p<0.01)

**Table 4. Pearson's correlation coefficients for pitch slope versus Clegg readings, Cmax and Kc for cricket pitches sampled across the region. Pitches are arranged in order of decreasing Clegg readings. Significant correlations at the 5% (\*) and 1% (\*\*) levels are indicated.**

Cricket Pitch	Clegg Reading	Cmax	Kc
3WS, Barbados, Pitch #2	0.256	0.337	0.157
CPK, Jamaica, Pitch #1	0.209	0.127	-0.175
3WS, Barbados, Pitch #3	0.345	0.403	0.146
3WS, Barbados, Pitch #4	0.304	0.224	-0.123
SAB, Jamaica, Pitch #4	0.461*	0.505*	0.125
BCG, Guyana, Pitch #2	-0.285	-0.280	-0.076
KNO, Barbados, Pitch #3	0.166	0.126	-0.013
UWI, Trinidad, Pitch #4	0.487*	0.573**	0.227

**Table 5. Spearman's correlation coefficients for pitch slope direction (absolute sine degrees) versus Clegg readings, Cmax, Kc and Slope for cricket pitches sampled across the region. Pitches are arranged in order of decreasing mean Clegg readings. Significant correlations at the 5% level (\*) are indicated.**

Cricket Pitch	Clegg Reading	Cmax	Kc	Slope
3WS, Barbados, Pitch #2	-0.219	-0.304	-0.182	-0.301
CPK, Jamaica, Pitch #1	-0.001	0.054	0.323	-0.449*
3WS, Barbados, Pitch #3	-0.474*	-0.424	0.020	-0.170
3WS, Barbados, Pitch #4	-0.013	0.015	-0.153	-0.141
SAB, Jamaica, Pitch #4	-0.397	-0.439	-0.309	-0.105
BCG, Guyana, Pitch #2	0.136	0.107	0.127	-0.273
KNO, Barbados, Pitch #3	0.152	0.139	0.061	-0.204
UWI, Trinidad, Pitch #4	-0.055	-0.052	0.172	-0.103