Sustainable and Safe Playing Surfaces for Australian Football League Sports Fields

Laboratory assessment of soil-water management and the effect of amendments on soil structural properties

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Executive Summary

The Australian Football League Queensland has been investigating options to improve the performance of its Premier League sporting fields in Brisbane. The resilience and performance of grassed surfaces on sports fields is strongly influenced by the underlying soil physical, chemical and biological properties. Compaction of the soil surface and the presence of fine-textured soil profiles have been shown to be the most common limiting factors in turf maintenance. However, the Premier League fields have been constructed with a wide range of soil materials. As a first step towards identifying appropriate soil management treatments to improve the performance of these playing surfaces, a laboratory evaluation was undertaken to characterise the effect of water applications and soil amendments on the subsequent physical and hydraulic properties of various soil profile materials. The specific objectives of this investigation were to:

- Evaluate the factors influencing the potential for structural degradation of soil surfaces;
- Evaluate the potential to modify surface hardness properties by the application of water (e.g irrigation/rainfall) prior to playing on these surfaces; and
- Evaluate the potential benefits of applying soil amendments on soil structural properties influencing agronomic responses, playability and injury risk.

Factors influencing the potential for structural degradation of soil surfaces

Soil texture has a dominant effect on the bulk density, hardness and shear strength of the soil surface. Sand was found to have a high bulk density which was relatively unaffected by either the level of compactive force applied or the soil moisture content at which the force was applied. In all cases, the penetration hardness was low due to the single grain structure of the sand soil. Increasing the compactive force applied was found to produce a slight increase in shear strength and made the surface slightly harder as measured by deformation.

The influence of both traffic (ie. compactive force applied) and soil moisture management on compaction and shear strength is greater for fields with sandy clay loam and clay soils. The level of traffic appears to be the dominant factor influencing changes in hardness suggesting that it is more important to manage playing load and rotate practice areas on fields with these soils. As the amount of traffic increases, the relative influence of initial moisture content on bulk density and hardness decreases. On high traffic fields or areas, the level of surface compaction created will be high irrespective of whether there is a high soil moisture content. However, restricting play on wet fields with sandy clay loam or clay soils, particularly where these fields do not normally experience high traffic loads, should significantly reduce the incidence of surface compaction and reduce the frequency of routine aeration treatments.

Potential to modify surface hardness properties by the application of water

Application of water to sand based profiles only provides a benefit where the surface is particularly dry and exhibits a low shear strength resulting in inadequate foot stability and traction. Only a small amount of water (i.e. 5 mm) needs to be added to maximise the cohesive forces and shear strength. This water can be added immediately prior to playing without risk of inducing additional compaction. For normally compacted sandy clay loams, extremely dry conditions can result in excessive surface hardness. In these cases, an application of 5-10 mm of water should be sufficient to produce a surface moisture content of 7-17 % and reduce the hardness to below critical levels. Applying larger amounts of water to sandy clay loam surfaces with little grass cover immediately prior to play may result in the surface exhibiting low shear strength and inadequate foot stability and traction.

Dry clay soils exhibit very high hardness values raising the risk of impact injuries. However, wet clay soil has a low shear strength which reduces foot stability and traction. Wet clay soils also have a high deformation potential which raises the risk of longer term structural degradation and agronomic impacts. Hence, clay soils should be managed to keep the moisture content within an optimal range. For the normally compacted clay soil the moisture should be in the range of 17 to 28 % volume. However, it should be noted that clay based soils should rarely dry out below 10% volumetric moisture content under field conditions and hence, the application of 5-10 mm of water should be sufficient to achieve the optimal surface soil moisture content. For clay soils, irrigation water should be applied at least 24 hours prior to play to reduce the risk of deformation and additional surface compaction.

Potential benefits of applying soil amendments on soil structural properties influencing agronomic responses, playability and injury risk

The incorporation of Hydrocell flakes into the soil profile did not produce any significant agronomic or playability improvements under the compacted conditions likely to be experienced on sporting fields. However, the incorporation of biosolids into the soil profile does appear to provide some agronomic and playability benefits. Agronomic benefits associated with improved soil-water capacity and internal drainage appear to be greatest on clay based profiles. The incorporation biosolids was also found to increase deformation and rebound suggesting that amended soils (particularly sand based profiles) would feel softer and more “springy” under foot potentially reducing the risk of injury. It is recommended that further research into the magnitude and longevity of benefits associated with the incorporation of biosolids be conducted under field conditions.

Topdressing with crumbed rubber was found to be an effective strategy to protect the underlying soil structure from compactive forces likely to be experienced in the field. Biosolid topdressing produced only marginal protective benefits on the underlying soil. Crumbed rubber deformation measurements suggest that it is will typically provide a softer surface with greater rebound potential than existing soil based surfaces. These characteristics would be expected to reduce player injury risk. Hence, it is recommended that the agronomic and playability benefits of topdressing with crumbed rubber be further evaluated under field conditions.

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Appendices

1 Introduction

Turf grasses on sports fields suffer a range of stresses caused by adverse soil physical, chemical and biological conditions (Carrow, 2000). Previous studies (eg. Hacker 1987, Carrow, 1990 & 2000) suggest that the most important factor influencing grass establishment and tolerance to wear is soil profile construction, with the over-riding influence being the effect of soil structure on the water infiltration, aeration and drainage rates (Figure 1.1). Similarly, declining turf quality under hot, humid summer conditions is exacerbated by poor soil aeration, excessive subsoil wetness, high temperatures and turfgrass diseases (Bigelow *et al*., 2001).

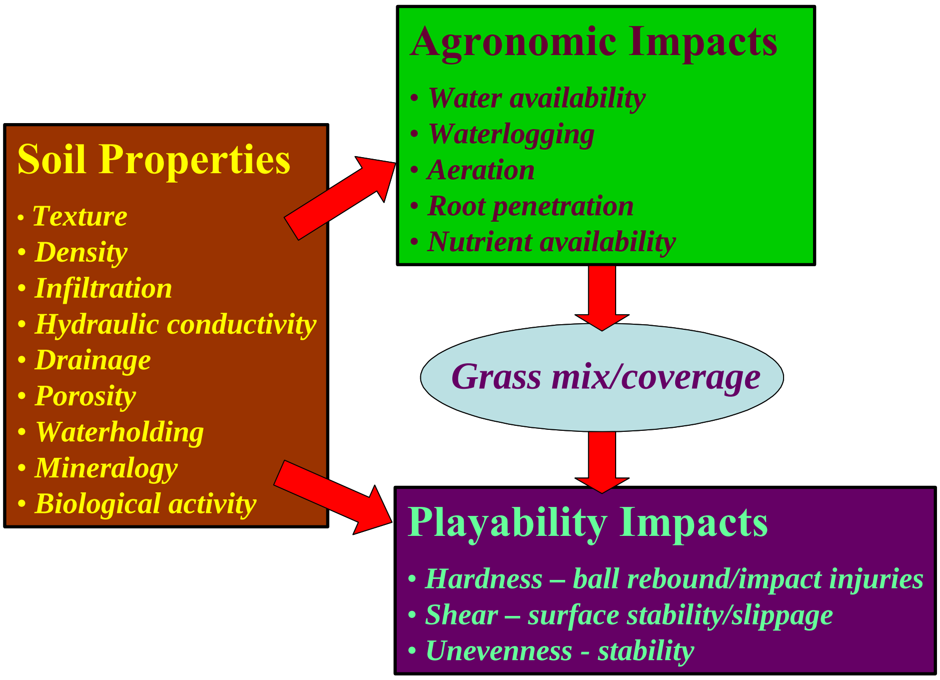

Figure 1.1 Conceptual model of soil properties influencing agronomic and playability factors as part of sports field management

Compaction of the soil surface and the use of excessively fine-textured (ie. clay and silt dominated) soil profiles have been shown to be the most common limiting factors in turf maintenance (Carrow, 1990; 2000). Soil compaction reduces oxygen diffusion, total water use and moisture extraction in the soil profile (Agnew and Carrow, 1985). The proportion of pore spaces >200 µm in diameter within the top 10-90 mm of the soil profile reduces over time due to compaction processes (Lodge and Baker, 1993). Soil structural degradation occurs through both man-made (eg. intensive use) and natural causes (eg. sodic dispersion or an accumulation of organic matter) with large differences being found between high and low wear areas.

Cultivation is often regarded as the primary means of alleviating these problems. Rapid physical deterioration of sporting field soil profiles has been observed even with high levels of spiking and sand top dressing (Gibbs and Baker, 1989). Hence, the benefits of cultivation are nearly always short lived (Carrow *pers comm*).

Sand content and type has also been found to strongly influence both air-filled pore space and moisture content. Soil profiles containing more than 94% sand have been found to provide adequate infiltration rates and air-filled pore space for sporting fields (Baker and Richards, 1993). However, shallow drained soils commonly used on Queensland community sporting fields and landscape sites tend to have higher clay contents, retain excess water and are poorly aerated with low drainage rates. Even soils with a high sand content have been found to suffer from reduced porosity. For example, drainage from a sandy loam soil profile was found to be inadequate with infiltration rates falling to 0.5 mm/h after only one season of usage (Baker and Canaway, 1990). Similarly, soil profile mixes with less than 60% added sand which were subjected to simulated foot traffic produced infiltration rates and air filled porosities which approached zero (Rashed *et al*., 1988).

The AFLQ is currently interested in improving the quality of its Premier League sporting fields with a focus on improving playability and reducing the risk of player injury. These fields have been constructed with a wide range of soil materials (Raine and Eberhard, 2004). To enable the identification of appropriate soil management treatments to improve the performance of these surfaces, a laboratory evaluation was undertaken to characterise the effect of irrigation applications and soil amendments on the physical and hydraulic properties of various soil profile materials. The specific objectives of this investigation were to:

- Evaluate the factors influencing the potential for structural degradation of soil surfaces;
- Evaluate the potential to modify surface hardness properties by the application of water (e.g irrigation/rainfall) prior to playing on these surfaces; and
- Evaluate the potential benefits of applying soil amendments on soil structural properties influencing agronomic responses, playability and injury risk.

This report provides an overview of the soils and measurement methods used in the laboratory study (Chapter 2) before reporting separately on the experiments undertaken to address each of these objectives (Chapters 3-5).

2 Common Materials and Methods

2.1 Soil Selection

Three soils (Table 2.1) were selected for study as representative of the soil texture range identified during the earlier characterisation of soil profiles on the AFLQ Premier League sporting fields (Raine and Eberhard, 2004). Field textures of the soils were determined using the method outlined in McDonald and Isbell (1990). The loamy sand was obtained from a local landscape supplier and was similar to soil material commonly provided as topdressing for sporting fields. The sandy clay loam was collected from the surface horizon of an alluvial soil located in the upper Lockyer Valley. The clay soil was collected from the Agricultural Engineering Field Station located at the University of Southern Queensland. The soils selected for treatment were air-dried, crushed to pass through a 4 mm sieve and homogenously mixed before being stored in air-tight containers. A particle size analysis was conducted by immersion wetting the 5 g of air-dried soil in 30 cm^3 of deionised water and applying approximately 100 J s^{-1} of ultrasonic (20 kHz) energy for a period greater than 15 minutes. The suspensions were transferred to a 500 cm^3 settling cylinder, made up to volume with deionised water and mixed homogenously. After the appropriate settling period, sub-samples were extracted with a pipette to determine the quantity of <2 µm and <20 µm equivalent spherical diameter particles. The sand sized fractions (Table 2.2) of the loamy sand were measured dry sieving a 1000 g sample for 90 minutes on a nest of sieves mounted on an Octagon 200 Variable Amplitude Test Sieve Shaker (Endecotts Limited, London, UK) at a vibration speed of 3000 revolutions per min with medium level amplitude.

Table 2.1 Physical properties of the selected soils

Field Texture	Particle size distribution (%)			Air-dried volumetric moisture content (%)
	<2 µm	2-20 µm	>20 µm	
Loamy sand	1	2	97	0.2
Sandy clay loam	11	1	78	3.5
Light-medium clay	60	22	18	10.0

Table 2.2 Distribution of the sand sized fractions for the loamy sand

Size Fraction (µm)	%
>1650	0.1
1180 - 1650	0.9
600 -1180	11.8
425 - 600	13.7
300 - 425	24.7
150 - 300	34.3
75 - 150	11.3
53 - 75	1.6
<53	1.6

2.2 Measurement of Soil Structural Properties

2.2.1 Bulk density

The soil bulk density is regarded as an indicator of soil compaction as both measures are directly related without being affected by other soil parameters. The bulk density of the compacted soil core was calculated from the oven-dried equivalent mass of the soil and the measured volume of the soil in the core.

2.2.2 Shear strength

The shear strength of the soil surface (5 mm depth) was measured using a handheld shear vane (Figure 2.1) manufactured by Geotest Instrumental Corp (Model E-285, Evanston, IL, USA). The vanes are pressed into the soil surface and a rotational force applied to the handle to shear the soil surface. The shear area can be adjusted using three different sized heads to accommodate for different levels of shear strength. The maximum shear strength of the soil surface is measured from the force required to shear the surface. The shear strength values reported in this work are in units of kg cm^{-2} which are equivalent to 98.1 kN m^{-2}.

Figure 2.1 Measuring soil surface shear strength using a shear vane

2.2.3 Surface hardness

Surface hardness of the soil cores was measured using a 0.25 cm^2 flat tipped (5.6 mm diameter) impact penetrometer with the impact energy (9.81 J cm^{-2}) delivered by dropping a sliding hammer (1.0 kg mass) over a distance of 0.25 m (Figure 2.2a). This penetrometer delivered the same energy per unit area as a drop penetrometer commonly used to assess surface hardness on sporting fields (e.g. Orchard, 2001). For field measurements, the hammer mass is dropped successively up to three times and the distance that the tip penetrates the soil surface is measured after each drop. However, due to the limited depth (60-70 mm) of the soil core samples in this trial, it was not always possible to obtain readings for each of the three consecutive drops.

Soil hardness was also evaluated by using a 11.46 cm^2 flat tip (38.2 mm diameter) probe attached to a load frame to apply a force of 2546 N or 222 N cm^{-2} to 58% of the sample area (Figure 2.2b). The force was approximately equal to that applied to field soils by a 100 kg person standing on a five studded boot where the whole force was applied via the studs. The maximum depth of probe penetration during the application of the force was measured and termed the “initial deformation”. As the force was released, the soil rebounds and the depth of penetration was again measured and termed the “long-term deformation”.

In some of the treatments, the penetration resistance was also measured with a handheld penetrometer (Zoli Maurizio, Alfonsine, Italy). A 60° cone tip with either 2.5mm or 3.5 mm diameter was pushed by hand into the samples to approximately 30 mm with constant speed (Figure 2.2c). The maximum force applied was read from the dial gauge and converted to MPa.

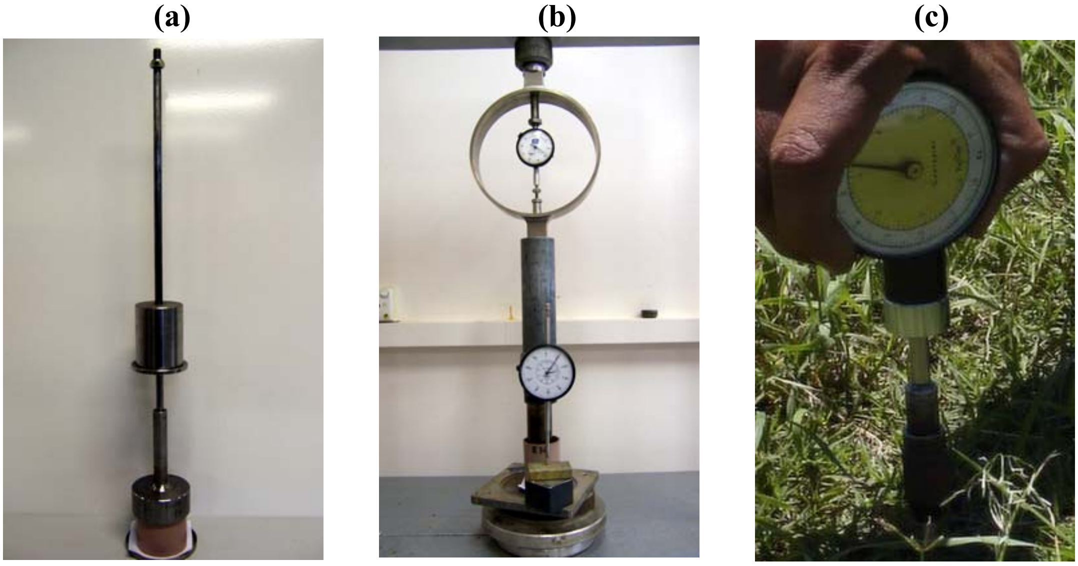

Figure 2.2 Measurement of soil hardness using (a) an impact penetrometer (b) a load frame fitted with flat tipped probe and (c) handheld penetrometer

2.2.4 Saturated hydraulic conductivity

Saturated hydraulic conductivity was measured by applying a constant head of water to the soil core samples (Figure 2.3). A length of PVC (70 mm length) was taped to the upper end of the PVC containing the treated soil core. Tap water was ponded in the PVC tube to a depth of approximately 60 mm above the soil core and allowed to drain until a steady state discharge was recorded (normally < 120 mins). The steady state discharge (flux) was measured and the saturated hydraulic conductivity calculated using Darcy's equation (Darcy 1856 cited in Jury and Horton, 2004).

Figure 2.3 Measurement of saturated hydraulic conductivity using a constant head apparatus

2.2.5 Total, air-filled and capillary porosity

The treated soil cores were saturated by placing them in a water bath so that the elevation of the soil surface was the same as the surrounding water level. After equilibration, the saturated soil cores were removed and weighed without drainage. The saturated soil samples were then placed on a low pressure (1 bar) suction plate and sequentially subjected to -40 and -80 cm head (equivalent to -4 and -8 kPa) applied by hanging column (Figure 2.4). Where the soil cores were amended with either Hydrocell flakes or biosolids, the samples were also placed on a 5 bar suction plate in a low pressure chamber and equilibrated at 33 kPa. The soil samples were weighed after equilibrium at each suction level and after final treatment were oven-dried before weighing. The total porosity of the treatment samples was calculated as the difference between the saturated and oven-dry weight of the soil. The air-filled (-4 and -8 kPa) porosity and the moisture content at 33 kPa were calculated using the measured weight at each equilibration level and the oven-dried mass.

Figure 2.4 Soil cores resting on a low pressure suction plate attached to a hanging water column used to equilibrate at either -4 or -8 kPa

2.3 Data Handling and Analysis

Five replications were conducted on all treatments except were specifically identified. An application specific database was developed using Microsoft Access to store and sort the measured and derived data. The database was subjected to several data coherence tests (identification of input errors, missing treatment series and measurements) to identify and rectify data entry errors. Where appropriate, a range of statistical analyses including analysis of variance, t-tests Tukey honestly significant difference tests and Tamhane's T2 tests were conducted using SPSS version 12.0.1 for Windows (SPSS Inc., Chicago, IL). All differences are significant at $P<0.05$ unless otherwise indicated.

3 Effect of Moisture Content and Compactive Force on Soil Structural Properties

3.1 Introduction

Community based sporting fields are often constructed using locally sourced soil materials. While there is sometimes an attempt to top-dress these profiles with a layer of sand, the surface soil on sporting fields in the Brisbane area have been found to range from sands to medium-heavy clays (Raine and Eberhard, 2004). A principal factor influencing soil structural degradation due to traffic is the compactive force (or pressure) applied. Similarly, the moisture content at which the force is applied has also been found to influence the magnitude of the resultant compaction. However, the majority of sporting field research has been conducted on light textured (ie. sand) based soils and there is no information available on the effect of these factors on the structural degradation of soils commonly found on community based sporting fields. Hence, this experiment was conducted to quantify the influence of compactive force, and the moisture content at which the force is applied, on structural degradation of soils commonly found on local community based sporting fields.

3.2 Materials and Methods

The experimental treatments involved sub-sampling each of the three air-dried soils (Chapter 2.1) and adding known water volumes to produce a range of moisture contents (Table 3.1). The sub-samples were then loosely packed into PVC cores (50 mm inner diameter, 70 mm height) and variously compacted (Table 3.1) with either a static force or dynamic energy applied to the upper surface (Figure 3.1). Five replications of each moisture and compaction treatment were used. The bulk density of the compacted cores was calculated and measurements of penetration, hardness and shear force conducted.

Table 3.1 Moisture added and compaction treatments applied to the soil cores

Soil texture	Moisture treatments (% vol water added)	Compaction treatments
Loamy sand	5, 10 or 15	8, 16 or 24 kg sample^{-1}; 3 J cm^{-2}
Sandy clay loam	7, 10 or 15	8, 16 or 24 kg sample^{-1}; 3 J cm^{-2}
Light-medium clay	5, 10 or 15	4, 8, 16 or 24 kg sample^{-1}; 1 or 3 J cm^{-2}

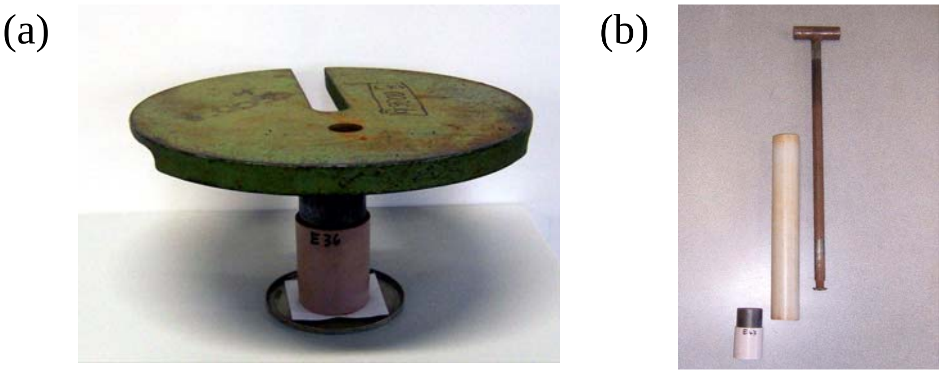

Figure 3.1 Compaction of the soil cores by either (a) static or (b) dynamic force

Correlation analyses were used to identify significant relationships between the variables. A stepwise multivariate regression was conducted to enable the development of a quantitative predictive relationship and the prediction of soil behaviour from soil properties (eg texture) and environmental conditions (eg moisture, compaction).

3.3 Results

Bulk density

Bulk density was found to be highly correlated with soil texture and was typically found to increase with increasing moisture content and force applied (Figure 3.2). However, at low moisture content and applied forces, bulk density was generally lower in higher clay content soils. The bulk density of the loamy sand under these conditions was ~1.5 g cm^{-3} while the sandy clay loam and clay had bulk densities of ~1.3 and ~1.05 g cm^{-3}, respectively.

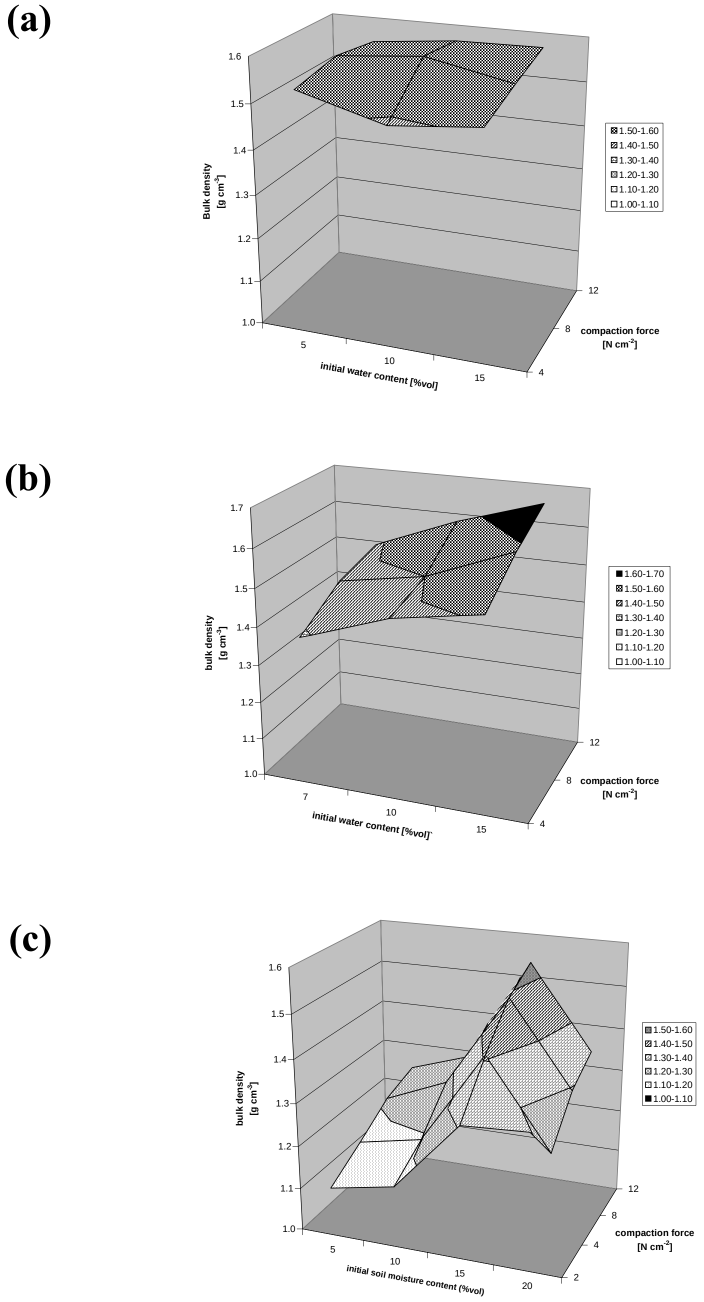

Figure 3.2 Effect of initial soil moisture content and compaction force/energy on bulk density of (a) loamy sand (b) sandy clay loam and (c) light-medium clay

For the loamy sand, there was no significant effect of initial moisture content on compaction and a relatively small effect of increasing force applied on compaction (Figure 3.2a).

However, for the sandy clay loam and clay both the moisture content of the soil when the force is applied and the magnitude of the force have a significant impact on the final bulk density (Figure 3.2b & c). Compaction of the clay is particularly sensitive to moisture content with a compactive force of 8 Nm^{-2} producing densities of 1.2-1.3 kg cm^{-3} at low (e.g. 5-10%) moisture contents but greater than 1.5 kg cm^{-3} when the initial moisture content was greater than 25 % by volume (15% added). The apparent decrease in bulk density at high moisture contents (ie. 20 % vol added) for the clay soil is an artifice of the confined cores and the incompressibility of the water in the samples. The correlation between the bulk density and the clay content of the soil, water content prior to compaction and the compactive forces applied are presented in Table 3.2.

Table 3.2 Pearson's correlation between bulk density and clay content, compactive force applied and water content prior to compaction

	Clay content	Water content prior to compaction	Compactive force applied
Bulk density	-0.801 **	-0.428 **	0.440 **

** Correlation is significant P>0.01 level (2-tailed).

The most important factor influencing the bulk density is the clay content of the soil. Initial moisture content and the compactive force applied had a smaller and more variable influence on the bulk density observed. This is consistent with Taylor (1980) who also found that soil texture was the most reliable parameter to estimate soil physical characteristics. A stepwise multivariate regression was conducted for these parameters (Appendix A.1) producing the relationship:

$$\rho_b = 1.337 - 0.007 * clay + 0.012 * \Theta_v + 0.012 * compactive\,force \qquad (r^2 = 0.78)$$

where: ρ_b = bulk density [g cm^{-3}]
clay = clay content [$\%_{weight}$]
θ_v = volumetric moisture content prior to compaction [$\%_{vol}$]
compactive force = force applied [N cm^{-2}]

This relationship highlights that increasing the clay content of the soil reduces the bulk density where as increasing the moisture content of the soil prior to compaction, and increasing the compactive force applied, both increase the bulk density.

Surface hardness

The hardness of the surface as measured by drop penetrometer was found to be largely influenced by the texture of the soil with the 0.25 cm^2 drop penetrometer penetrating more than 60 mm into the loamy sand cores on the first drop irrespective of the initial moisture content or the compactive force that had previously been applied to the core. However, for the sandy clay loam, the first drop penetrated less than 60 mm for all treatments except where the soil was very wet (15% vol added) and only lightly (ie. 4 or 8 N cm^{-2}) compacted (Table 3.3). At lower moisture contents, the application of higher compactive forces (and hence, bulk densities) resulted in a decrease in penetration. However, this effect decreased with increasing moisture content of the sample. The second drop penetrated more than 60 mm on all treatments of the sandy clay loam.

Table 3.3 Depth of penetration by a drop penetrometer on a compacted sandy clay loam

Water added prior to application of compactive force (% vol)	Compactive force applied (N cm^{-2})	Penetration depth (mm)
7	4	55
	8	43
	12	36
10	4	53
	8	52
	12	44
15	4	>60
	8	>60
	12	52

The moisture content of the soil at which the compaction occurs also appears to be the major determinant of drop penetration on the clay with both first and second drop measurements of less than 60 mm recorded on drier samples (ie. 5 or 10 %vol added) but first drop measurements of more than 60 mm recorded for wet samples even after high levels of compaction (Figure 3.3).

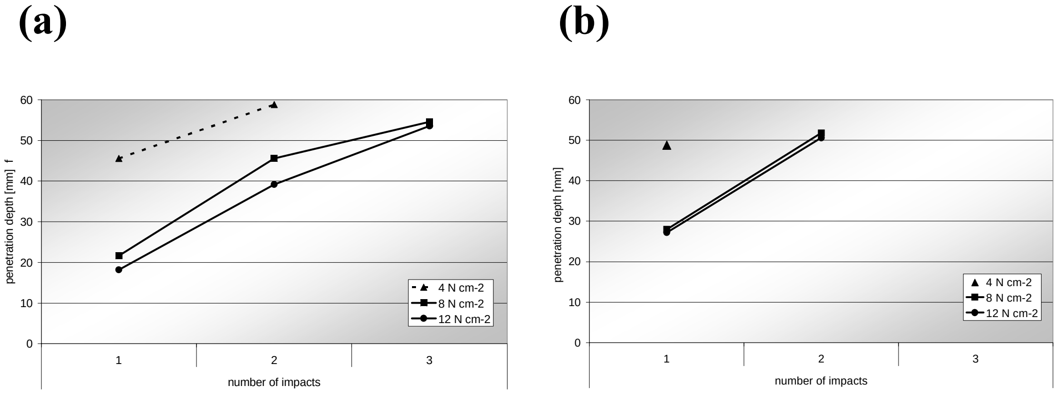

Figure 3.3 Drop penetrometer depth on a clay soil with (a) 5% and (b) 10% volume water added and previously subjected to either 4 (▲), 8 (■) or 12 (♦) N cm^{-2} of compactive force

The surface deformation as measured using the large tipped penetrometer driven by the load frame at constant speed/force is also highly correlated with the soil texture. Deformation (ie. penetration) distance is smallest in the loamy sand and greatest in the clay (Figure 3.4). The initial deformation is always higher than the long-term deformation regardless of the initial water content and the compaction force applied due to the rebound properties of the soil material. Absolute rebound (i.e. the difference between initial and long term deformation) normally increases with clay content and hence, is greatest in high clay content soils.

The soils were typically softer (i.e. larger deformation measured) when exposed to low compactive forces under relatively dry conditions (Figure 3.4). For all soils, the standard deviation in deformation was higher in the samples exposed to low compaction at low moisture content (i.e. low bulk density soils) than in the soils where high compactive force had been applied. For the loamy sand, compaction and initial moisture content had relatively little impact on deformation (Figure 3.4a). However, moisture content of the sandy clay loam strongly influenced the deformation irrespective of the compactive force previously applied to the sample although there was a slight increase in hardness (ie. decrease in deformation) with

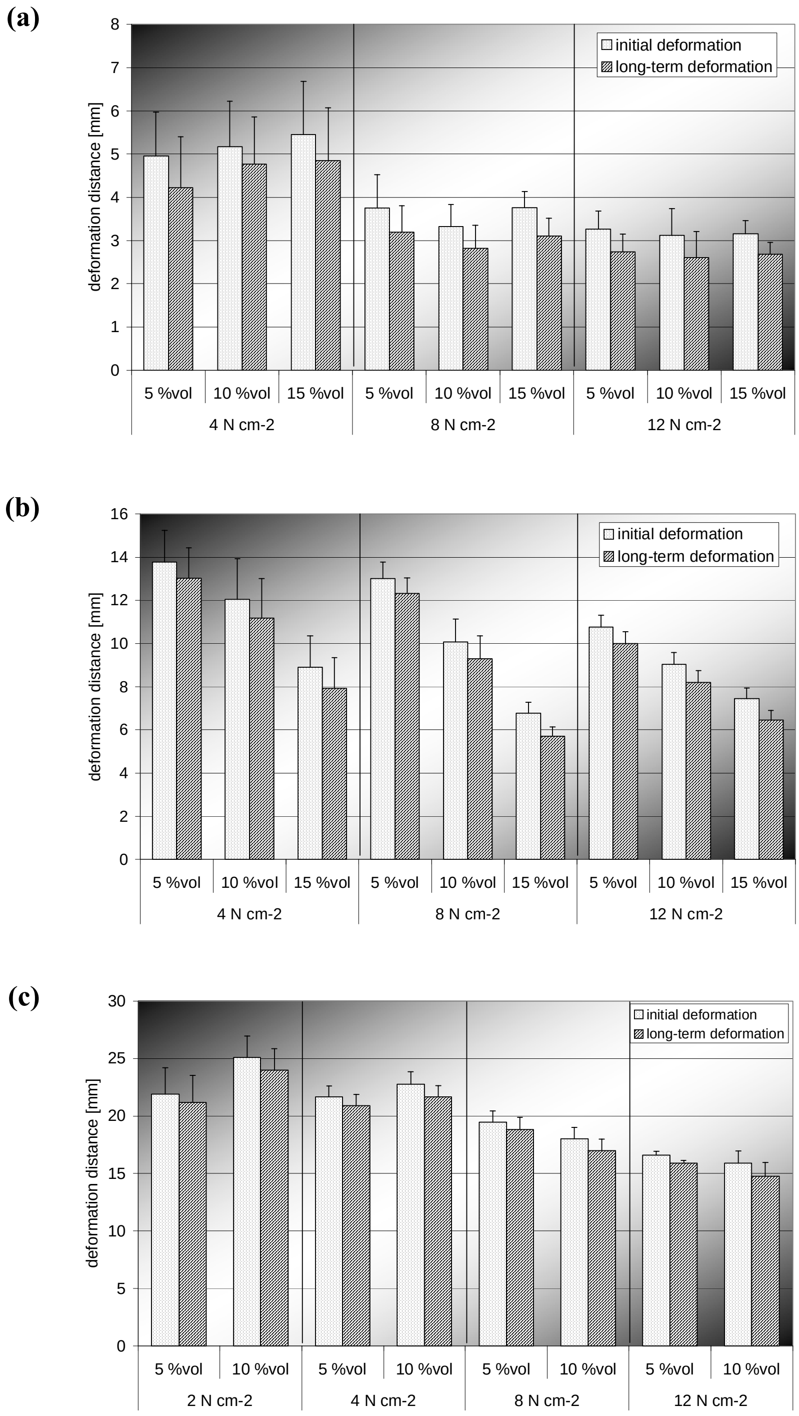

Figure 3.4 Deformation characteristics of (a) loamy sand (b) sandy clay loam and (c) light-medium clay as affected by soil moisture and compactive force applied

increasing compactive force (Figure 3.4b). The deformation level of the clay was generally higher than that of the other soils (Figure 3.4c). There was little effect of moisture content over the range evaluated while hardness increased with compactive force. However, increasing moisture content beyond the range shown significantly increased deformation in the clay as these samples could not bear the force applied and the deformation measured by the penetrometer was greater than the depth of the cores.

Shear strength

The shear strength of the soil surface is predominantly influenced by soil texture with the loamy sand requiring a small force (<0.1 kg cm^{-2}) to shear while the sandy clay loam and clay required larger forces of 0.1-0.35 and 0.2-0.6 kg cm^{-2}, respectively (Figure 3.5). The difference in shear strength due to initial moisture content was greater than the difference due to the compactive force applied for each soil. However, the nature of the change in shear strength with increasing moisture content varied between the soils. For the loamy sand, increasing the initial moisture content resulted in a surface with a higher shear strength (Figure 3.5a). However, increasing initial moisture content reduced the shear strength of the surface on the sandy clay loam (Figure 3.5b) and had comparatively little effect on the clay (Figure 3.5c). The compactive force applied to the soil had no significant effect on shear strength in the loamy sand (Figure 3.5a). However, increasing the compactive force applied significantly increased the shear strength of the soil for both the sandy clay loam and clay (Figure 3.5b & c; Appendix A.4).

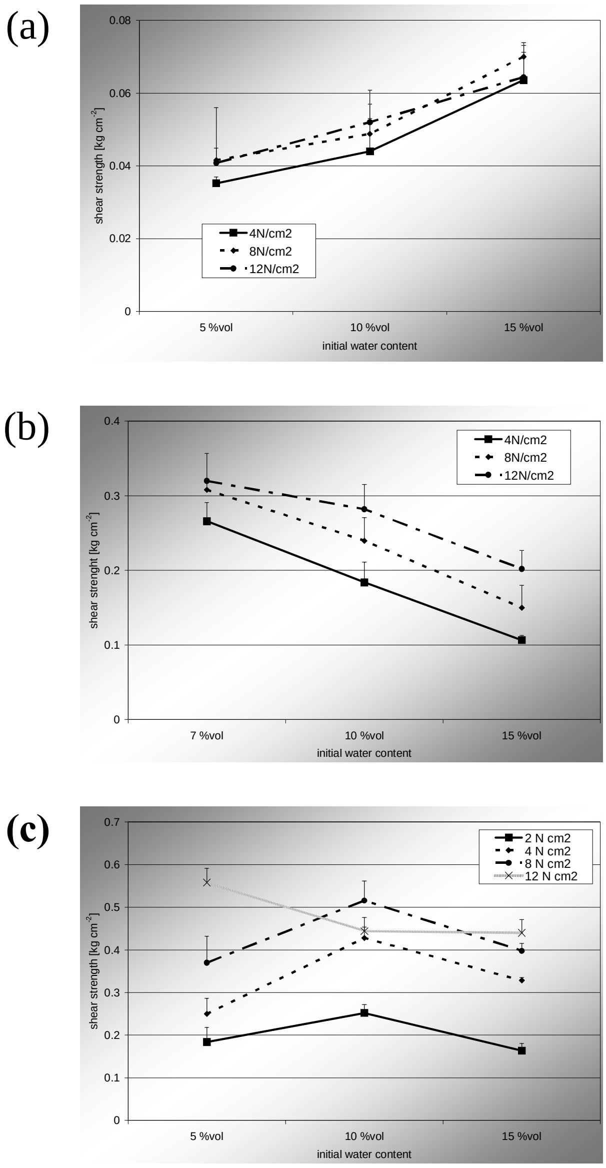

Figure 3.5 The effect of initial moisture content and compactive force applied on the subsequent shear strength of (a) loamy sand, (b) sandy clay loam and (c) light-medium clay

3.4 Discussion

This experiment investigated the effect of soil construction material and management factors which lead to the creation of degraded playing surfaces. The results confirm that soil texture has the dominant effect on surface hardness and shear strength. It also demonstrated that the structural degradation of soil surfaces is highly influenced by both the compactive force applied and the moisture content at which the force is applied. However, the magnitude, and in some cases the direction, of changes in the soil structural properties is heavily dependent on the soil texture.

The effect of management on the different soil materials highlights the need to identify and promote appropriate management practices for community based fields based on soil profile properties. For example, the bulk density, hardness and shear properties of loamy sand surfaces (ie. commonly found on elite sporting surfaces) are not greatly influenced by either the application of compactive forces or the soil moisture content at which force is applied. Hence, these fields can be played on under wet conditions with a relatively low risk of resultant soil surface degradation. However, the density, and hardness of sandy clay loam and clay based surfaces are greatly influenced by both traffic and the moisture content of the field when the traffic is applied.

The management practices applied to recently laid or aerated sandy clay loam and clay soils will influence the period of time taken to compact the surface and the maximum density and hardness reached. The level of traffic appears to be the dominant factor influencing changes in hardness on these soils suggesting that it is important to manage playing load and rotate practice areas on fields with these soils. As the amount of traffic increases (i.e. the level of compactive force applied increases), the relative influence of initial moisture content on bulk density and hardness decreases. On high traffic fields or areas, the level of surface compaction created is likely to be high irrespective of whether there is a high soil moisture content. Hence, reducing traffic on high use fields would appear to be more effective in reducing the rate of soil compaction than manipulation of the soil moisture. However, areas subject to high traffic loads (e.g. goal mouths and centre squares) will rapidly deteriorate irrespective of soil moisture management and are more likely to require regular aeration or rejuvenation to maintain hardness values within acceptable ranges.

The effect of soil moisture management on minimising structural degradation would appear to be most beneficial low traffic fields or areas with sandy clay loam or clay soils. Under these conditions, minimising traffic during periods when the field is wet will greatly reduce the incidence of structural decline. The result of traffic management during wet periods on these soils would be a reduction in the requirement for aeration and rejuvenation and/or an increase in the period between when these practices are required.

3.5 Conclusions

Soil texture has a dominant effect on the bulk density, hardness and shear strength of the soil surface. Sand was found to have a high bulk density which was relatively unaffected by either the level of compactive force applied or the soil moisture content at which the force was applied. In all cases, the penetration hardness was low due to the single grain structure of the sand soil. Increasing the compactive force applied was found to produce a slight increase in shear strength and made the surface slightly harder as measured by deformation.

The influence of both traffic (ie. compactive force applied) and soil moisture management on compaction and shear strength is greater for fields with sandy clay loam and clay soils. The level of traffic appears to be the dominant factor influencing changes in hardness suggesting that it is more important to manage playing load and rotate practice areas on fields with these soils. As the amount of traffic increases, the relative influence of initial moisture content on bulk density and hardness decreases. On high traffic fields or areas, the level of surface compaction created will be high irrespective of whether there is a high soil moisture content. However, restricting play on wet fields with sandy clay loam or clay soils, particularly where these fields do not normally experience high traffic loads, should significantly reduce the incidence of surface compaction and reduce the frequency of routine aeration treatments.

4 Effect of Water Application on Soil Surface Properties

4.1 Introduction

Surface hardness is commonly associated with the incidence of shin splints and an increased risk of shoulder and knee injuries problems (e.g. Powell and Trotter, 2000). Many studies (e.g. Baker *et al.*, 1999; Newell and Wood, 2000; Baker, 2001) have shown strong relationships between the soil physical properties of moisture content, penetration resistance and surface hardness on sand based profiles. Similarly, watering of sporting fields prior to use has been found to reduce surface hardness values and influence ball rebound (Mooney and Baker, 2000). Hence, irrigation management is often used as a method to manage firmness and playability of the soil profile surface (e.g. Powell and Trotter, 2000). However, the effect of moisture content on surface hardness would be expected to be both soil texture and density related, two factors which are highly variable on community based sporting fields in Queensland. Hence, there is a need to more clearly identify these relationships across the range of soil conditions encountered on community playing fields so that the benefit of alternative irrigation management practices appropriate to the soil conditions and sport being played can be quantified. This experiment was conducted to evaluate the impact of watering on the hardness, shear strength and impact penetration for a range of soil textures.

4.2 Materials and Methods

Air-dried samples of three soils (loamy sand, sandy clay loam and light-medium clay) were packed into soil cores as per the process outlined in Chapter 3. A single compaction treatment was applied using either the static or dynamic forces as outlined in Chapter 3 to create bulk densities equivalent to those observed in the field for similarly textured soils (Raine and Eberhard, 2004). A density of approximately 1.57, 1.49 and 1.45 g cm^{-3} was created on the loamy sand, sandy clay loam and light-medium clay, respectively. To simulate the impact of rainfall or irrigation on the physical properties of the soil surface after compaction had already occurred, the soil cores were then oven-dried at 105 ºC for 48 hours before applying between 0 and 25 mm of tap water (electrical conductivity ~ 0.45 dS m^{-1}) to the soil surface (Table 4.1). There were five replications of each treatment. The wetted samples were covered with plastic and allowed to equilibrate for a minimum of 12 hours before the hardness, shear strength and penetration resistance of the soil surface was measured. Multiple impacts were used consistent with the practice of multiple impacts used in field evaluations using the drop penetrometer.

Table 4.1 Volumetric moisture content of the soil cores after water application

Soil	Water applied (mm)	Volumetric moisture content (%)
Loamy sand	5	9.6
	10	18.3
	15	26.9
	20	35.8
	25	41.5
Sandy clay loam	5	9.2
	10	18.2
	15	27.8
Light-medium clay	5	8.5
	10	17.6
	15	28.3
	20	35.4

4.3 Results

Surface hardness

The application of water to the soil cores was found to reduce surface hardness. Depth of penetration measured using the drop penetrometer was also related to soil texture with less penetration recorded on the clay soil (ie. hardest soil) and greater penetration on the loamy sand (e.g. softest). The first drop penetration depth for the light medium clay and sandy clay loam ranged from 7-43 mm and 3-53 mm, respectively. However, the first drop on the loamy sand was greater than 60 mm for each water treatment. For the sandy clay loam and light-medium clay, successive impacts with the penetrometer increased the depth of penetration by progressively smaller distances.

Increasing the volume of water applied was found to significantly increase the penetration depth measured using the drop penetrometer on both the sandy clay loam and light-medium clay (Figure 4.1). However, the effect of water application on hardness was not linear. For example, applying 5 mm of water to the clay soil produced no difference in the hardness of the soil measured using the drop penetrometer while adding 10 mm and 15 mm increased penetration depth by an additional 10 mm and 18 mm on the first drop, respectively. Adding 20 mm of water increased the penetration depth by an additional 37 mm. The effect of water application on the loamy sand was not able to be quantified using the drop penetrometer as the depth of penetration in all cases was >60 mm.

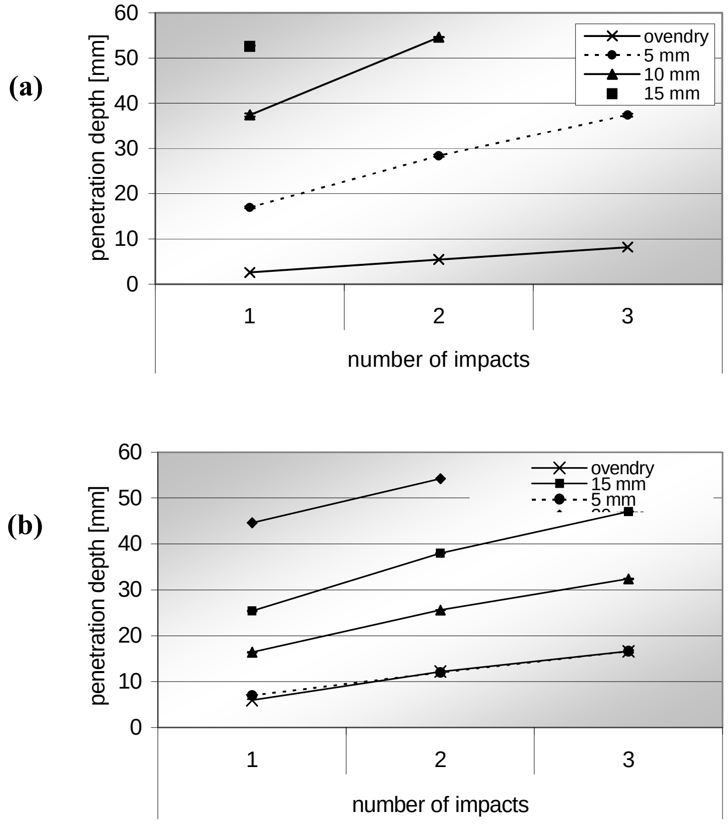

Figure 4.1 The effect of water application on the depth of impact penetration for oven-dried (a) sandy clay loam (bulk density = 1.49 g cm^{-3}) and (b) light-medium clay (bulk density = 1.45 g cm^{-3})

Increasing the volume of water applied to the clay soil was also found to produce a significant difference (Table 4.2; Appendix C.1) in surface hardness as measured using the handheld penetrometer (60° angle, 2.5 or 3.5 mm cone tip).

Table 4.1 Effect of water application on penetration resistance of a clay

Water applied to oven-dried soil	Penetration resistance (MPa)
0 mm	>23.00 *
5 mm	20.76 ^{d}
10 mm	8.03 ^{c}
15 mm	3.28 ^{ab}
20 mm	1.17 ^{a}

* exceeded penetrometer scale

Surface deformation as measured using the large tipped probe driven by the load frame at constant force was highly correlated with soil texture (Figure 4.2). The deformation of the loamy sand was comparatively small (i.e. <10 mm) irrespective of water content while deformation in the clay soil ranged from 2 to 32 mm. In all cases, the deformation was significantly affected by the amount of water added.

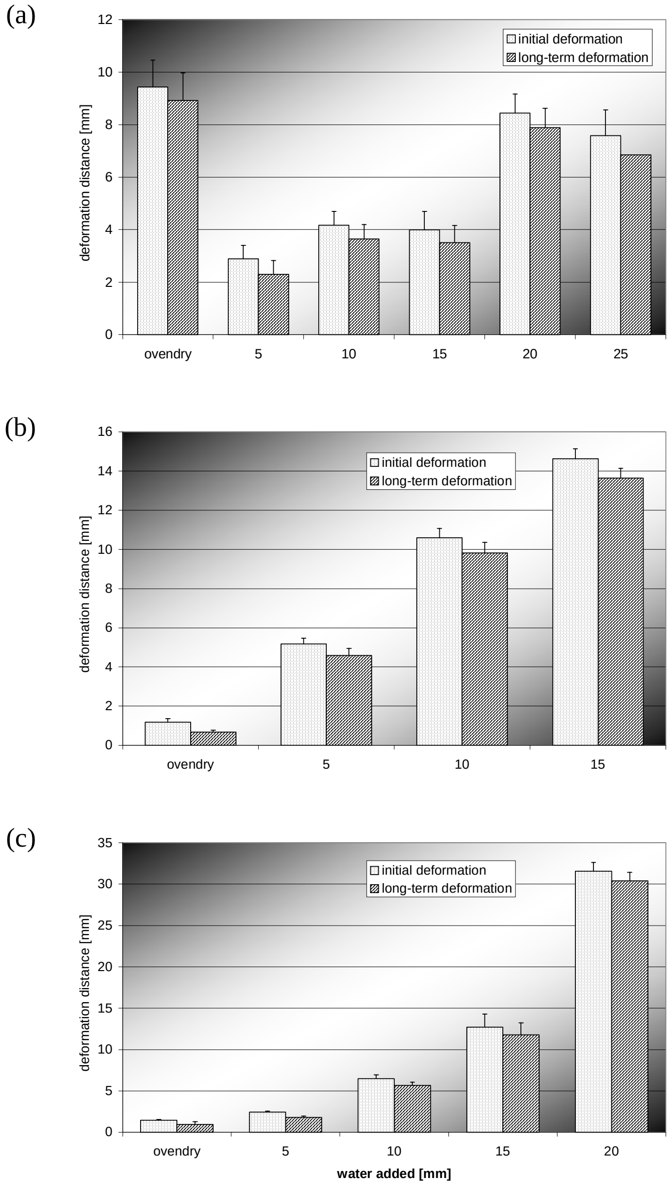

Figure 4.1 Effect of water addition on the surface deformation of (a) loamy sand (b) sandy clay loam and (c) light-medium clay

When the loamy sand is dry, it has little cohesive binding and a high level of deformation due to its single grain structure (Figure 4.2a). Adding a small amount of water increased the cohesion between the sand particles resulting in a decrease in the deformation and an increase in surface hardness. There was little difference in deformation when between 5 and 15 mm of water was applied. However, there was a significant increase in deformation when more than 20 mm of water was added to loamy sand.

For both the sandy clay loam and light-medium clay, deformation was smallest in the dry soil and increased significantly with the addition of water (Figure 4.2b & c). There was no significant difference between the deformation measured on the oven-dried treatment and 5 mm water applied to the clay. However, applying 5 mm of water to the sand clay loam did increase deformation. Where only small amounts of water (5-10 mm) were applied, the clay soil was found to deform less than the sandy clay loam. However, there was no significant difference in the deformation of each soil when 15 mm was applied. Applying 20 mm of water to the clay soil significantly increased deformation suggesting that the moisture content was approaching a critical consistency phase.

Shear strength

The shear strength of the dry light-medium clay was up to ten times greater than that of the sandy clay loam and almost 100 times higher than that of the loamy sand. However, the application of water to the soils significantly affected the shear strength of the surfaces (Figure 4.3). The effect was greatest in the clay soil where the application of even small amounts of water (e.g. 5 mm) significantly reduced the surface shear strength and the application of 20 mm of water reduced the surface shear by an order of magnitude (Figure 4.3c). There was no change in the shear strength of the sandy clay loam when only 5 mm of water was applied but shear strength was reduced by the application of 10 and 15 mm of water on this soil (Figure 4.3b). The application of water to the loamy sand did not greatly influence the shear strength (Figure 4.3a) with applications of between 5 and 20 mm of water resulting in a relatively small but significant increase in shear strength. However, there was no significant difference between the shear strength of the oven-dried loamy sand and the soil where 25 mm of water had been applied (Figure 4.3a).

4.4 Discussion

Managing soil hardness by addition of water

The application of water to dry soil was found to significantly reduce both soil surface hardness and shear strength. However, the magnitude of the effect is a function of soil texture with a relatively small effect on sand based profiles and larger changes experienced on clays. A relationship between Clegg hammer and 1st drop penetrometer measurements has been identified (Henderson, *pers comm*) for a range of local sporting fields as part of the field benchmarking component of this project. Using this relationship (clegg reading = 18.321 * 1st drop penetrometer (in cm) ^ -0.7468; $r^2 = 0.79$) and the desirable range of clegg readings for sporting fields (~7-15), the optimal range of first drop penetrometer readings would be between 1.3 and 3.5 cm. Values in this range were obtained for the clay soil when 10 and 15 mm of water was added (moisture contents of 17-25%) and for the sandy clay loam when 5 and 10 mm of water were added to oven dried soil (moisture content of 8-17%). The hardness of the loamy sand was below the maximum acceptable level irrespective of moisture content.

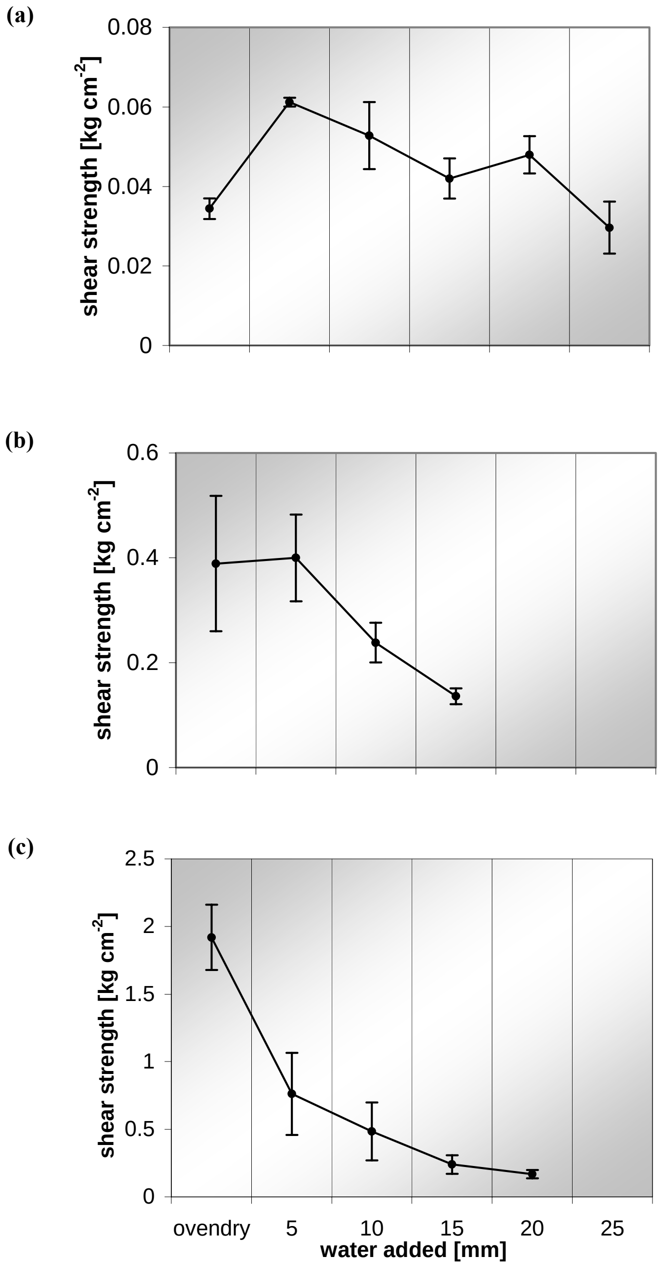

Figure 4.3 Effect on shear strength of water applied to oven-dried (a) loamy sand, (b) sandy clay loam and (c) light-medium clay

Effect of moisture on foot stability and traction

Traction and foot stability may become a problem where the shear strength of the soil surface is low while there is potential for ligament and muscle injuries when shear strength is too high. However, it should be noted that the shear strength experienced by players on sporting fields is a function of both the grass and soil surface. The shear strength of the sand based surfaces is very low due to the single grain structure and low cohesion between individual particles. This highlights one of the major player injury risks associated with the use of sand based profiles on sporting fields where there are low levels of stoloniferous surface grass cover due to either inappropriate establishment, grass selection or excessive wear. The application of water to sand based profiles increases inter-particle cohesion and hence, shear strength. Thus, where surface instability is a problem on sand based profiles, the application of small amounts of water could be used to increase traction. However, the effect is relatively small and over-application of water will reduce the effect. As the moisture content of the loamy sand approaches saturation, the water films around the particles enable the particles to slip readily past each other and shear decreases to values similar to that of oven-dried soil (Figure 4.3a). These results are consistent with traditional understanding of shear stresses in sands (e.g. Craig, 1992).

Traction on fields with sandy clay loam or clay based surface layers is significantly greater than that of sand based surfaces except where excessive water has been applied (eg. on heavy clay cricket pitches). For soils with even relatively small amounts of clay, shear strength increases rapidly as the surface dries. Hence, the application of small amounts of water to these soils can be used to reduce shear strength. However, when these surfaces are very wet (eg. 20 mm or more water added to the compacted light-medium clay) they have low shear strength and hence, would provide poor foot traction. This may present as a problem on clay based sporting fields during and after rainfall or where irrigation water has been applied immediately prior to play.

Potential for surface damage

One of the major factors influencing compaction is the moisture content of the soil when the compactive force is applied (Chapter 3). Hence, when games are played on wet fields there is a risk that surface compaction will be further increased leading to exacerbated agronomic (e.g. reduced aeration, infiltration, grass cover) and surface playability (e.g increased hardness) problems. This is one of the major reasons why fields may be closed during and/or after periods of rainfall. However, over-application of irrigation water prior to games in an effort to reduce hardness and influence traction also increases the risk of increasing surface compaction. The comparatively high deformation measurements associated with the clay soils indicates that the risk of exacerbating compaction and increasing surface unevenness is greater in clay than in sand based profiles. For clay soils, deformation increased dramatically after the application of 20 mm of water.

4.5 Conclusions

Application of water to sand based profiles only provides a benefit where the surface is particularly dry and exhibits a low shear strength resulting in inadequate foot stability and traction. The benefits are also likely to be greater on surfaces where there is little stoloniferous grass cover. Only a small amount of water (i.e. 5 mm) needs to be added to maximise the cohesive forces and shear strength. This water can be added immediately prior to playing without risk of inducing additional compaction.

For normally compacted sandy clay loams, extremely dry conditions can result in excessive surface hardness. In these cases, an application of 5-10 mm of water should be sufficient to produce a surface moisture content of 7-17 % and reduce the hardness to below critical levels. Applying larger amounts of water to sandy clay loam surfaces with little grass cover immediately prior to play may result in the surface exhibiting low shear strength and inadequate foot stability and traction.

Dry clay soils exhibit very high hardness values raising the risk of impact injuries. However, wet clay soil has a low shear strength which reduces foot stability and traction. Wet clay soils also have a high deformation potential which raises the risk of longer term agronomic and structural degradation. Hence, management of clay soils requires keeping the moisture content within an optimal range. For the normally compacted clay soil used in this work it appears that the moisture should be in the range of 17 to 28 % volume. However, it should be noted that clay based soils should rarely dry out below 10% volumetric moisture content under field conditions and hence, the application of 5-10 mm of water should be sufficient to achieve the optimal surface soil moisture content. For clay soils, irrigation water should be applied at least 24 hours prior to play to reduce the risk of deformation and additional surface compaction.

5 Evaluating the Potential to Improve Soil Structural Properties using Soil Amendments

5.1 Introduction

Soil amendments may be used to improve both agronomic and playing conditions. They may be either physical or chemical in nature and generally aim to reduce compaction, maintain infiltration and drainage rates, and/or improve turf establishment and resilience. The most common physical amendments applied to sporting fields are sand and peat while the most common chemical amendment is gypsum. Physical amendments may be either applied as top-dressing or incorporated into the soil profile.

Topdressing evens the surface of the field, helps prevent thatch build up by providing a more favourable environment for micro-organisms, and prolongs the effects of aeration. Sand has been the most commonly applied topdressing material. However, the benefits of top-dressing are highly variable with some treatments not affecting turfgrass quality (eg. Dunn *et al.*, 1995). Annual top-dressing with a soil material similar to that of the growing medium may enhance root development. However, use of inappropriate topdressing materials may act to reduce infiltration, internal drainage, aeration and root penetration. Topdressing with crumbed rubber has been found to reduce compaction and hardness, maintain infiltration rates and increase surface temperature (Rogers *et al.*, 1998). Crumbed rubber additions to the soil profile have also been found to enhance the physical properties of soils susceptible to compaction and add resiliency to sports turf (Groenevelt *et al.*, 1998).

Where physical amendments (e.g. sand, crumbed rubber) are incorporated into clay soils they act by increasing the average particle and pore size. Physical amendments (eg. peat, zeolite, clay, light expanded clay) are also commonly incorporated into sand soils to increase water holding capacity and nutrient retention. For example, incorporation of 5% peat by volume to sand profiles was found to increase the water storage capacity by up to 15% (Munster, 1998).

Given the range of potential amendment options, methods of application and the effect of texture on the potential benefits associated with different amendments, this experiment was conducted to evaluate the benefits associated with the use of some of the more promising soil amendments.

5.2 Materials and Methods

Three different soil amendments were evaluated on each of the loamy sand, sandy clay loam and light-medium clay soils. Hydrocell was evaluated as an incorporated amendment while crumbed rubber was evaluated only as a top-dressing. Biosolids were evaluated as both incorporated and top-dressed amendments.

Commercially available Hydrocell flakes (Fytogreen Aust Pty Ltd, Mt Eliza, Victoria) between 6 and 13 mm in diameter (Figure 5.1a) were uniformly mixed at a rate of 15% by volume into each of the three soils. A commercially sourced biosolid product (Figure 5.1b) (Amgrow Sports Field Revitalizer) which consisted of 80% composted organics, 15% composted biosolids and 5% composted chicken manure was obtained from Envirogreen Pty Ltd (Stapylton, Queensland). This product (Table 5.1) was passed through a 10 mm sieve and uniformly mixed with each soil at a rate of 50% by volume. Five replications of the loamy sand, sandy clay loam and light-medium clay soils amended with either the Hydrocell or biosolid were loosely packed into PVC tubes (50 mm internal diameter and 70 mm height) and compacted to densities normally encountered under field conditions by applying either 8 N cm^{-2}, 12 N cm^{-2} or 1.05 J cm^{-2}, respectively.

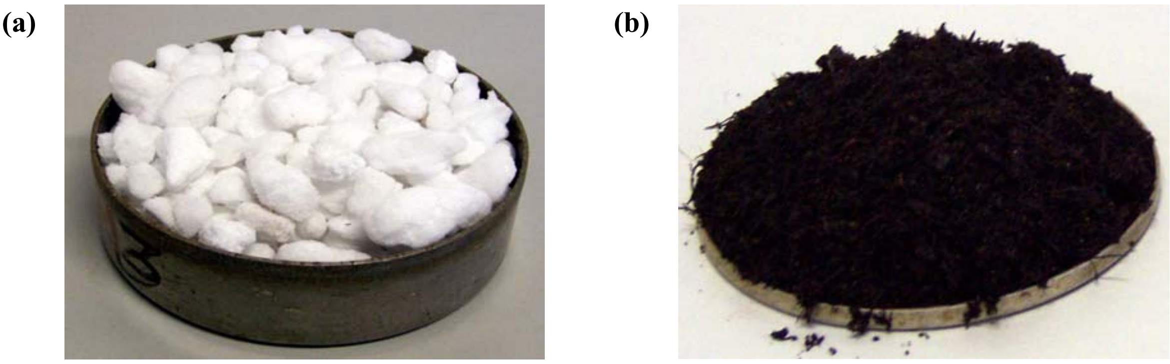

Figure 5.1 (a) Hydrocell and (b) biosolid amendments used in the trial

Table 5.1 Nominal properties[1] of the Amgrow Sports Field Revitalizer

Bulk density	1.03 g cm^{-3}
Organic matter	13 % (by weight)
Infiltration rate	13 mm min^{-1}
particles >20mm	<0.1 % (by weight)
particles 10-20mm	<0.1 % (by weight)
pH	7.3
Electrical conductivity	1.4 dS m^{-1}
Permeability	20 cm $hour^{-1}$

[1] Data provided by supplier

Loamy sand, sandy clay loam and light-medium clay soil cores which had not been amended were also compacted using the same force and energy treatments as above and used for the topdressing treatments. Two different types of crumbed rubber and two different rates (10 or 20 mm) of topdressing were evaluated. The crumbed rubber products evaluated (Figure 5.2) were (i) Crown III (Reclaim Industries, WA) which has a particle size of 0-2 mm and (ii) bulk crumbed rubber with a particle size of 0-6 mm supplied by Chip Tyre Pty Ltd, Ipswich, Queensland. Biosolid topdressing treatments applied at either 10 or 20 mm thickness to a normally compacted sandy clay loam soil core were also evaluated. After topdressing, the cores were subjected to an additional compaction to simulate conditions under normal field traffic. The loamy sand and sandy clay loam cores were subjected to 3 J cm^{-2} while the clay soil was subjected to 1 J cm^{-2}. The lower level of compaction was applied to the clay soil as 3 J cm^{-2} was found to induce a high level of compaction which did not differentiate between treatment effects on this soil. A control treatment involving each of the unamended soils without topdressing but subjected to both the initial and subsequent compaction treatments was also constructed. Measurements on the soil and topdressed treatments included hardness, shear strength, penetration resistance as well as saturated hydraulic conductivity and water/air filled porosity at different suction levels. The effect of compaction on the bulk density and saturated hydraulic conductivity of the crumb rubber treatments was also investigated.

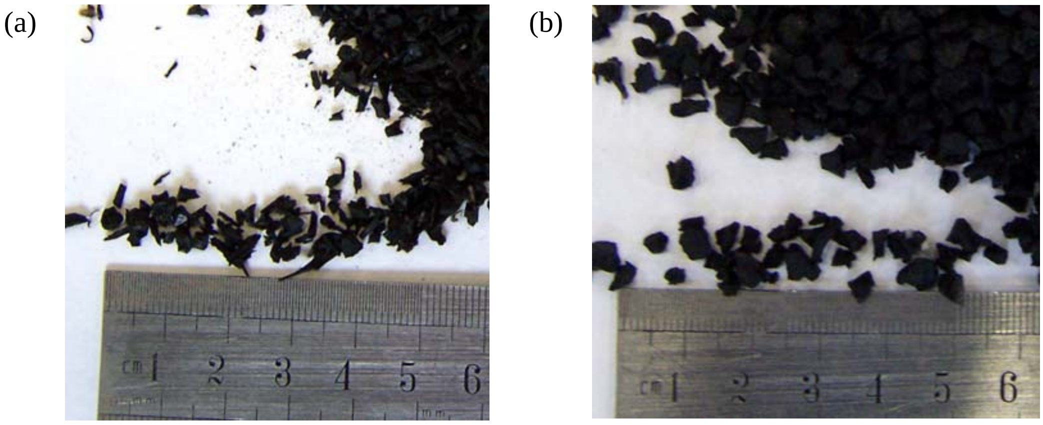

Figure 5.2 Image of (a) Crown III (0-2 mm) and (b) bulk (0-6 mm) crumbed rubber amendments

5.3 Results

5.3.1 Effect of incorporated amendments

Soil hardness

Incorporating biosolid at a rate of 50 % by volume significantly reduced the bulk density of each soil with the bulk density decreasing with increasing clay content (Table 5.2). Incorporation of the hydrocell flakes also produced a small, but significant, reduction in the bulk density of the loamy sand and sandy clay loam but had no significant effect on the bulk density of the clay soil. There was no significant difference in the penetration resistance measured using a handheld penetrometer on an unamended clay soil and a biosolid amended clay soil (Table 5.3). Penetration resistance was significantly reduced on this soil by the addition of Hydrocell.

Table 5.2 Effect of incorporating amendments on soil bulk density

Soil	**Amendment**	**Average bulk density [A] ($g\ cm^{-3}$)**	**Change in bulk density (%)**
Loamy sand	Unamended	1.57^{c}	
	50 % biosolid	1.25^{a}	- 20.4
	15 % Hydrocell	1.55^{b}	- 1.3
Sandy clay loam	Unamended	1.49^{c}	
	50 % biosolid	1.11^{a}	- 25.5
	15 % Hydrocell	1.46^{b}	- 2.0
Light-medium clay	Unamended	1.45^{b}	
	50 % biosolid	1.07^{a}	- 26.2
	15 % Hydrocell	1.44^{b}	ns

[A] $P<0.05$ within column for individual soil type only

Table 5.3 Effect of incorporated amendments on penetration resistance of a clay profile as measured with a handheld penetrometer

Treatment	Penetration resistance (MPa)
Control – no amendment	3.96^{b}
50% biosolid	4.10^{b}
15% Hydrocell	2.68^{a}

Depth of impact penetration was primarily related to soil texture with the lowest penetration in the clay soil and highest in the loamy sand soil. For all treatments, the depth of penetration by the first drop impact on the loamy sand was greater than 60 mm. For the sandy clay loam, there was no significant difference in the depth of first or second drop penetration between unamended, biosolid or Hydrocell treatments (Figure 5.3a). Biosolids and Hydrocell flakes incorporated into the light-medium clay typically increased the depth of penetration indicating that these treatments reduced soil hardness (Figure 5.3b). However, while there were significant differences in hardness between the unamended soil and the Hydrocell treatment for each of the three drop impacts, the biosolid amended soil displayed a significant difference for only the second and third drop impact on the clay soil (Figure 5.3; Appendix C.10).

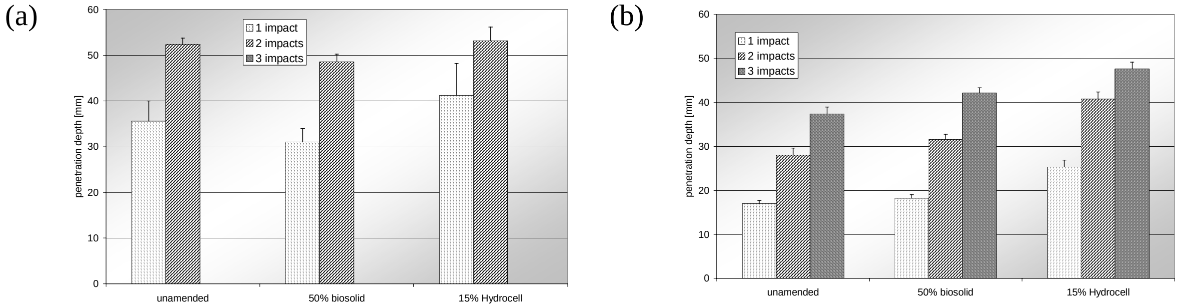

Figure 5.3 Effect of amendment incorporation on the depth of impact penetration for (a) sandy clay loam and (b) light-medium clay

The incorporation of biosolids or Hydrocell resulted in an increase in the amount of deformation produced by the application of 222 N cm^{-2} force (Figure 5.4). Biosolids produced the largest change with an approximate 300% increase in deformation compared to the deformation measured in the unamended loamy sand and a 48% increase in deformation compared to the unamended clay (Appendix C.4). Rebound in the biosolid amended treatment was also greatly increased and ranged from 14% of the initial deformation in the clay soil to 24% of the initial deformation in the loamy sand. Incorporation of Hydrocell flakes increased deformation by approximately 71% in the loamy sand and by 42% in the clay soil. Amendment with Hydrocell had no effect on rebound for any of the soils.

Shear strength

The effect of amendment incorporation on shear strength was variable between the soils. Incorporation of Hydrocell had no significant effect on shear strength in the loamy sand and sandy clay loam but significantly reduced the shear strength of the light-medium clay (Figure 5.5). The incorporation of biosolids did no produce any significant difference in shear strength compared the unamended soil profile for any of the soil textures. However, there was a significant difference in shear identified between the Hydrocell amended profile and the biosolid amended profile for both the sandy clay loam and clay soils (Appendix C.12).

Soil-water retention and porosity

The incorporation of biosolids significantly increased the total porosity of each soil and moisture held at low suctions (Table 5.4). The increase in moisture retention was greatest in the loamy sand with the biosolid mix increasing moisture content from 12 % to more than 30 % at 8 kPa with a relatively small decrease in air-filled porosity from 26 to 20 %. While there was no increase in moisture holding capacity in the clay soil at 8 kPa due to the incorporation of the biosolids, air-filled porosity increased from 5 to 12 %.

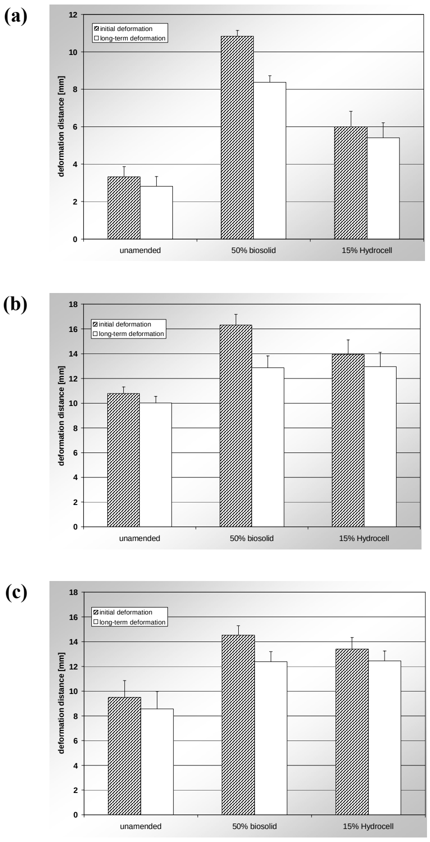

Figure 5.4 The effect of incorporated amendments on deformation of (a) loamy sand, (b) sandy clay loam and (c) light-medium clay

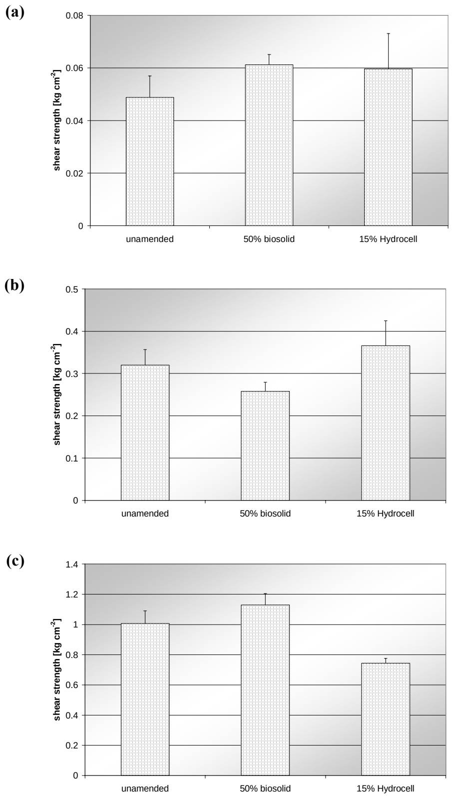

Figure 5.5 Effect of incorporated amendments on the shear strength of (a) loamy sand, (b) sandy clay loam and (c) light-medium clay

The Hydrocell incorporation produced a significant increase in total porosity in both the loamy sand and clay soils however, there was no difference in total porosity in the sandy clay loam. There was also no significant difference in the amount of water held at either 4, 8 or 33 kPa due to the incorporation of Hydocell for any of the soil textures except for a small reduction noted in the loamy sand at 8 kPa (Table 5.4). The incorporation of Hydrocell significantly increased the air-filled porosity in the sandy clay loam and clay soils at both 4 and 8 kPa. However, there was no effect of Hydrocell incorporation on air-filled porosity in the loamy sand (except at 8 kPa) nor in any of the soils at 33 kPa.

Table 5.4 Effect of incorporated amendments on porosity and soil-water

Soil	**Treatment**	**Total porosity**	**4 kPa**		**8 kPa**		**33 kPa***	
			Moisture content	**Air-filled porosity**	**Moisture content**	**Air-filled porosity**	**Moisture content**	**Air-filled porosity**
Loamy sand	Unamended	38.4^a	13.1^a	25.3^b	12.3^b	26.1^b	4.7^a	33.7^a
	50% biosolid	52.9^c	32.8^b	20.5^a	32.2^c	20.6^a	23.7^b	39.2^b
	15% Hydrocell	40.6^b	13.9^a	26.7^b	9.2^a	31.4^c	5.1^a	35.5^a
Sandy clay loam	Unamended	39.8^a	31.0^a	8.8^a	23.6^a	16.2^a	19.3^b	20.5^a
	50% biosolid	53.4^b	39.6^b	13.8^b	37.6^b	15.9^a	30.1^a	23.3^a
	15% Hydrocell	41.0^a	28.8^a	12.3^b	22.8^a	18.3^b	20.2^b	20.8^a
Light-medium clay	Unamended	46.7^a	45.2^a	1.6^a	42.1^a	4.6^a	40.2^a	6.5^a
	50% biosolid	56.0^c	54.2^b	5.8^c	48.3^b	11.7^c	38.7^a	15.6^b
	15% Hydrocell	49.9^b	46.2^a	3.6^b	41.4^a	8.5^b	43.0^a	6.8^a

^{A} $P<0.05$ within column for individual soil type only

* average and statistic on 3 replications only

Hydraulic conductivity

The effect of incorporating amendments on saturated hydraulic conductivity appears to be heavily dependent on the soil texture. Incorporation of biosolids reduced the saturated hydraulic conductivity in both the loamy sand and sandy clay loam but significantly increased the saturated hydraulic conductivity in the light-medium clay (Figure 5.6). Conversely, the addition of Hydrocell produced a significant reduction in saturated hydraulic conductivity for the loamy sand and light-medium clay soil but a significant increase in conductivity for the sand clay loam (Figure 5.6; Appendices C.13-18).

5.3.2 Effect of applying topdressed amendments

Surface hardness

Topdressing with crumbed rubber typically protected the underlying soil from the applied compactive force (Table 5.5). The difference in bulk density between the treatments topdressed with crumbed rubber and the untreated soils was between 0.1 and 0.2 g cm^{-3}. For the loamy sand, there was no difference in bulk density of the underlying soil irrespective of the crumb size or the depth of topdressing. However, for the sandy clay loam, topdressing with 20 mm of crumbed rubber was much more effective at preventing compaction of the underlying soil than using 10 mm depth. There was no difference between the effectiveness of the 0-2 and 0-6 mm size crumb on the sandy clay loam. There was no difference between either crumb size or the depth of crumbed rubber topdressing on the bulk density of the underlying light-medium clay. However, increasing thickness did reduce the size of the change in density due to compaction after topdressing (Table 5.5). Increasing the thickness of the crumbed rubber also reduced penetration resistance on the clay soil for the small crumb size (0-2mm) but had no effect for the 0-6 mm crumb material (Table 5.6; Appendix C.28).

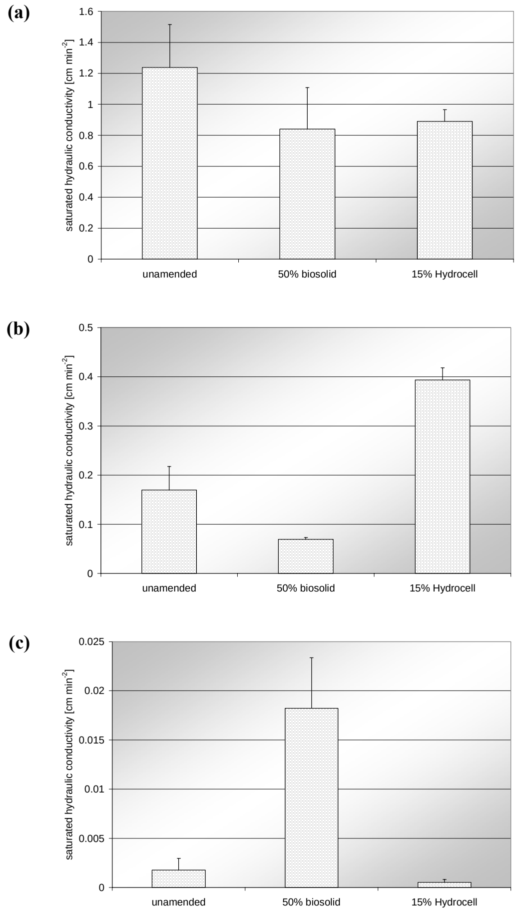

Figure 5.6 Effect of soil amendments on saturated hydraulic conductivity of (a) loamy sand, (b) sandy clay loam and (c) light-medium clay

Table 5.5 Effect of topdressing with crumbed rubber topdressing on the bulk density of the underlying soil

Soil	**Size of crumbed rubber (mm)**	**Depth of topdressing (mm)**	**Average bulk density (g cm^{-3})**	**Increase in bulk density due to compaction after topdressing (%)**
Loamy sand	no amendment	0	1.72^{b}	9.3^{d}
	0-2	10	1.66^{a}	3.8^{a}
	0-2	20	1.64^{a}	4.4^{ab}
	0-6	10	1.64^{a}	7.1^{bcd}
	0-6	20	1.64^{a}	6.1^{ac}
Sandy clay loam	no amendment	0	1.74^{c}	18.2^{d}
	0-2	10	1.70^{b}	15.2^{c}
	0-2	20	1.56^{a}	11.0^{ab}
	0-6	10	1.70^{b}	12.8^{bc}
	0-6	20	1.64^{a}	10.4^{a}
Light-medium clay	no amendment	0	1.57^{b}	9.9^{d}
	0-2	10	1.45^{a}	5.8^{c}
	0-2	20	1.48^{ab}	3.0^{a}
	0-6	10	1.50^{ab}	5.2^{bc}
	0-6	20	1.48^{ab}	3.5^{ab}

[A] $P<0.05$ within column for individual soil type only

Table 5.6 Effect of topdressing and on penetration resistance of a clay profile as measured with a handheld penetrometer

Product	Depth of topdressing (mm)	Penetration resistance (MPa)
Control	0	9.37^{c}
Crown III (0-2 mm)	10	8.25^{bc}
	20	6.87^{a}
Bulk (0-6 mm)	10	7.19^{ab}
	20	9.01^{c}

Application of the crumbed rubber as a topdressing also protected the underlying soil making it softer as measured using the impact drop penetrometer (Figure 5.7; Appendices C.29-30). First drop impacts on the loamy sand typically penetrated the entire sample depth (max. 60 mm) so the effect of crumb rubber topdressing was unable to be established for this soil. However, increasing the depth of topdressing from 10 to 20 mm protected the underlying sandy clay loam from compaction and significantly increased the penetration depth measured. There was no significant difference in penetration depth due to the crumb size used in the topdressing. For the clay, there was no significant difference in depth of penetration due to either crumb size or depth of topdressing (Figure 5.7b).

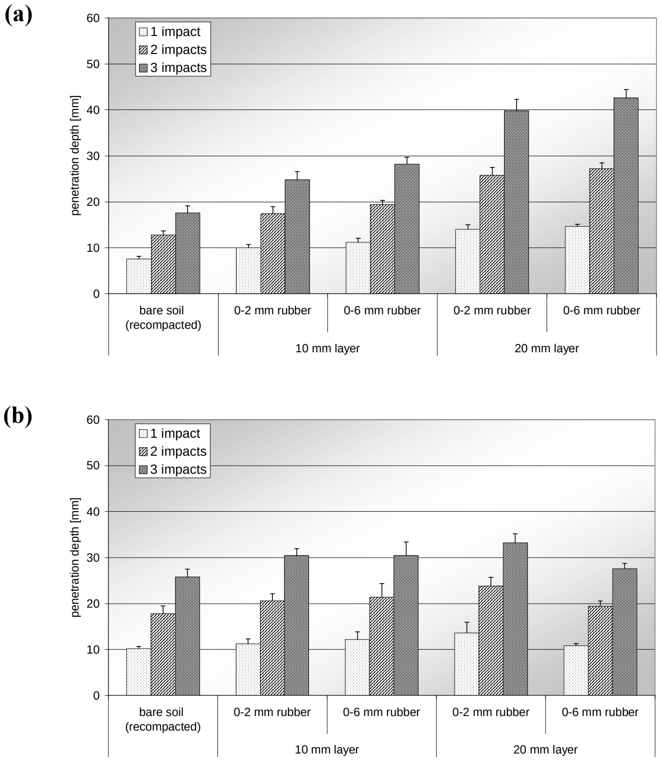

Figure 5.7 Effect of crumb rubber topdressing on impact drop penetrometer depth of underlying soil for (a) sandy clay loam and (b) light-medium clay
(measured after removing the topdressing)

The effect of topdressing with crumbed rubber on the deformation characteristic of the underlying soil varies depending on the texture of the underlying soil, the crumb size used and the depth of topdressing applied (Figure 5.8). On a loamy sand, only the application of 20 mm of the coarse (0-6 mm) crumb rubber had any significant effect on the deformation characteristic of the soil (Figure 5.8a; Appendix C.31). However, as there is relatively little deformation experienced on sands in any case, and the absolute difference measured was small, it would be difficult to justify applying crumbed rubber topdressing to improve deformation characteristics on a sand. Applying a topdressing of crumb rubber to either the sandy clay loam or clay protected the underlying soil from compaction and increased the deformation characteristic (Figure 5.8). For both soils, increasing the depth of topdressing significantly increased the level of protection achieved (Appendices C.32-33). In general, the coarser (0-6 mm) crumbed rubber was more effective at protecting the underlying surface but the differences was only significant for the 20 mm depth of topdressing applied to the clay soil.

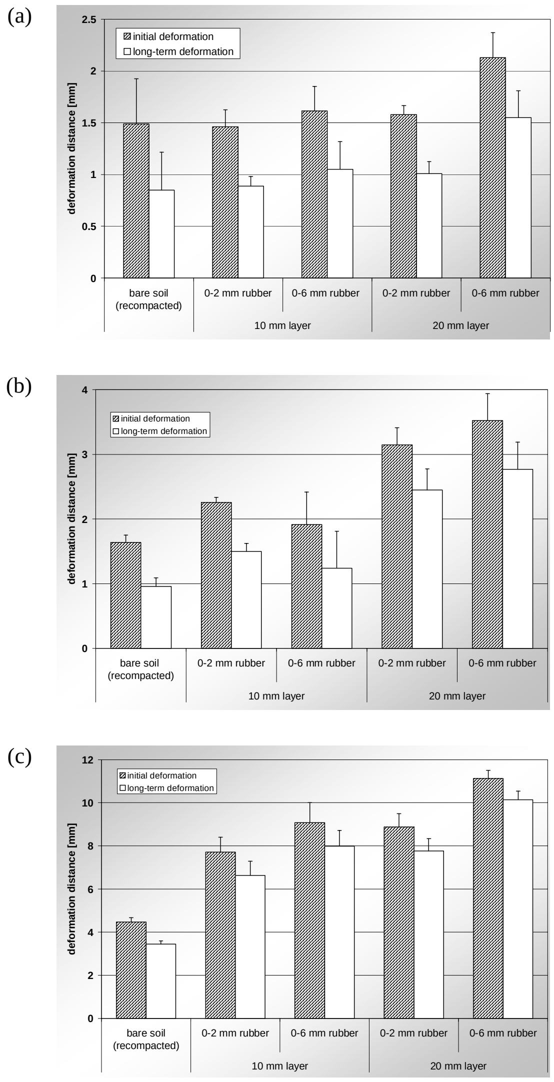

Figure 5.8 Effect of topdressing with crumbed rubber on soil surface deformation of the underlying (a) loamy sand, (b) sandy clay loam and (c) light-medium clay
(measured after removing the topdressing)

Under field conditions, the players experience the characteristics of the topdressed material overlying the soil profile. Where surface deformation was measured with either biosolids or crumbed rubber topdressing in place, the topdressing was shown to provide significantly greater deformation than bare soil after compaction. (Figure 5.9; Appendix C.8). In all cases, increasing the depth of topdressing significantly increased product effectiveness. However, the biosolid application provided only a relatively small improvement over the bare soil with the 20 mm biosolid application having higher hardness (ie. less deformation) than the 10 mm crumbed rubber treatments. The coarser (0-6 mm) crumbed rubber treatments produced marginally higher deformation than the finer (0-2 mm) crumbed rubber at both the 10 and 20 mm depth of application. Only the application of a 20 mm thick layer of 0-6 mm crumbed rubber produced an initial deformation approaching that of the uncompacted bare soil.

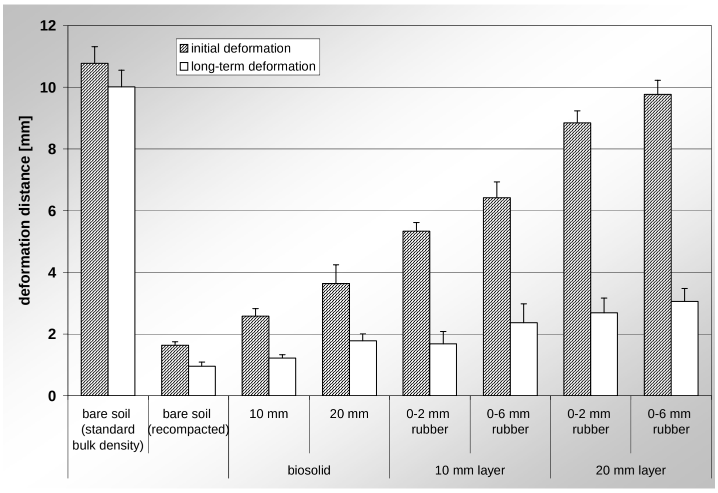

Figure 5.9 Effect of topdressing material on the deformation of a sandy clay loam
(measured with topdressing in place)

Shear Strength

The application of crumbed rubber as a topdressing had no significant effect on the shear strength of the underlying soil surface after compaction. There was no differences between soil textures nor between crumbed rubber size or depth of application (Figure 5.10' Appendices C.34-36).

Soil-water and porosity

The effect of topdressing with crumbed rubber on the porosity and soil-water properties of an already pre-compacted soil profile varies with soil texture and the size of the crumb rubber used (Table 5.7). In general, total porosity increased with increasing depth of crumbed rubber application and there was no significant difference due to the size of the crumbed rubber used. However, where 20 mm of crumbed rubber was applied, the use of the coarser (0-6 mm) crumbed rubber produced a significantly higher total porosity in the sandy clay loam but a lower total porosity in the clay soil compared with the use of the finer (0-2 mm) crumbed rubber. For a loamy sand, application of crumbed rubber as a topdressing typically reduced moisture holding capacity and increased the air-filled porosity at both 4 and 8 kPa. However, where 20 mm on the 0-6 mm crumbed rubber was applied, there was no significant reduction in moisture holding or change in air-filled porosity compacted to the bare soil. For the sandy clay loam and clay soils, application of crumbed rubber as a topdressing significantly increased both moisture holding at 4 kPa but had no effect at 8 kPa. For the sandy clay loam, air-filled porosity was increased at both 4 and 8 kPa. However, for the clay, the air-filled porosity at 4 kPa increased under the crumbed rubber but there was no effect at 8 kPa.

The high rates of saturated hydraulic conductivity measured after compaction (27.4 - 82.4 cm min^{-1}) of the crumbed rubber (Table 5.8) confirms that even under compacted conditions

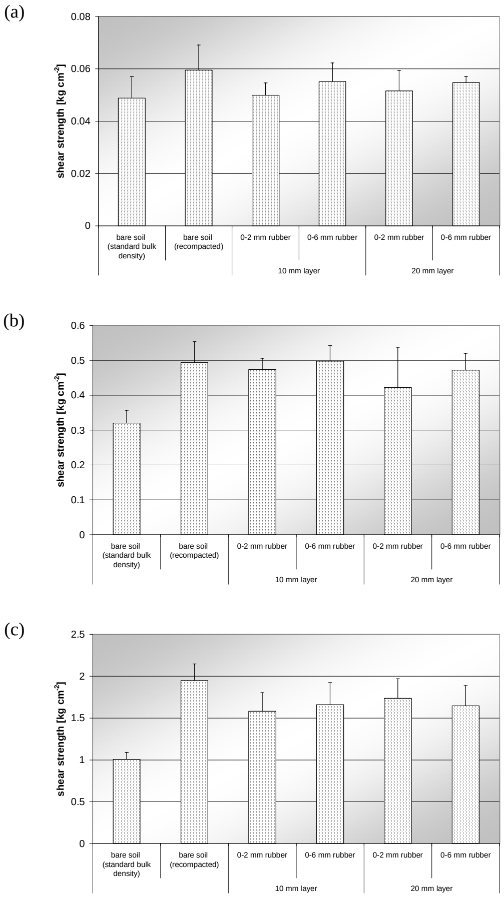

Figure 5.10 Effect of crumbed rubber topdressing on the shear strength of the underlying (a) loamy sand, (b) sandy clay loam and (c) light-medium clay
(measured after removing the topdressing)

Table 5.7 Effect of topdressing with crumbed rubber on soil-water properties and porosity of underlying soil

Soil	Depth of topdressing (mm)	Size of crumbed rubber (mm)	total porosity	4 kPa		8 kPa	
				Moisture content	Air-filled porosity	Moisture content	Air-filled porosity
Loamy sand	0	na	32.19 ^{a}	15.48 ^{b}	16.71 ^{a}	14.81 ^{c}	17.37 ^{a}
	10	0-2	32.68 ^{a}	11.66 ^{a}	21.02 ^{bc}	11.00 ^{a}	21.68 ^{bc}
	10	0-6	32.06 ^{a}	11.25 ^{a}	20.81 ^{bc}	10.76 ^{a}	21.30 ^{bc}
	20	0-2	35.30 ^{b}	11.98 ^{a}	23.32 ^{c}	11.35 ^{ab}	23.95 ^{c}
	20	0-6	34.47 ^{b}	14.95 ^{b}	19.52 ^{ab}	14.16 ^{bc}	20.31 ^{ab}
Sandy clay loam	0	na	29.18 ^{a}	27.63 ^{a}	1.55 ^{a}	24.70 ^{a}	4.48 ^{a}
	10	0-2	38.05 ^{c}	32.56 ^{c}	5.48 ^{c}	24.69 ^{a}	13.36 ^{c}
	10	0-6	38.04 ^{c}	32.42 ^{bc}	5.62 ^{c}	24.93 ^{a}	13.10 ^{c}
	20	0-2	34.54 ^{b}	31.17 ^{b}	3.37 ^{b}	23.91 ^{a}	10.64 ^{b}
	20	0-6	44.21 ^{d}	35.49 ^{d}	8.72 ^{d}	24.34 ^{a}	19.88 ^{d}
Light-medium clay	0	na	40.25 ^{a}	38.99 ^{a}	1.26 ^{a}	38.28 ^{a}	1.97 ^{a}
	10	0-2	42.27 ^{ab}	41.00 ^{b}	1.27 ^{a}	38.93 ^{a}	3.35 ^{bc}
	10	0-6	42.93 ^{b}	41.02 ^{b}	1.91 ^{a}	40.04 ^{ab}	2.89 ^{ab}
	20	0-2	45.64 ^{c}	44.66 ^{c}	0.98 ^{a}	41.33 ^{b}	4.31 ^{c}
	20	0-6	42.69 ^{b}	40.92 ^{ab}	1.76 ^{a}	39.13 ^{a}	3.56 ^{bc}

^{A} $P<0.05$ within column for individual soil type only crumbed rubber topdressing should not limit the rate of infiltration or internal drainage within the profile. Topdressing with crumbed rubber had no significant effect on the saturated hydraulic conductivity of an underlying loamy sand (Figure 5.11a). However, for the sandy clay loam, hydraulic conductivity was significantly higher under topdressed treatments

Table 5.8 Effect of compaction on density and hydraulic conductivity of the Crown III (0-2 mm) and bulk (0-6 mm) crumbed rubber topdressing amendments

Product	Compaction	Bulk density (g cm^{-3})	Saturated hydraulic conductivity (cm min^{-1})
Crown III (0-2 mm)	No compaction	0.44	75.4
	Compacted at 3 J cm^{-2}	0.58	27.4
Bulk (0-6 mm)	No compaction	0.48	152.8
	Compacted at 3 J cm^{-2}	0.61	82.4

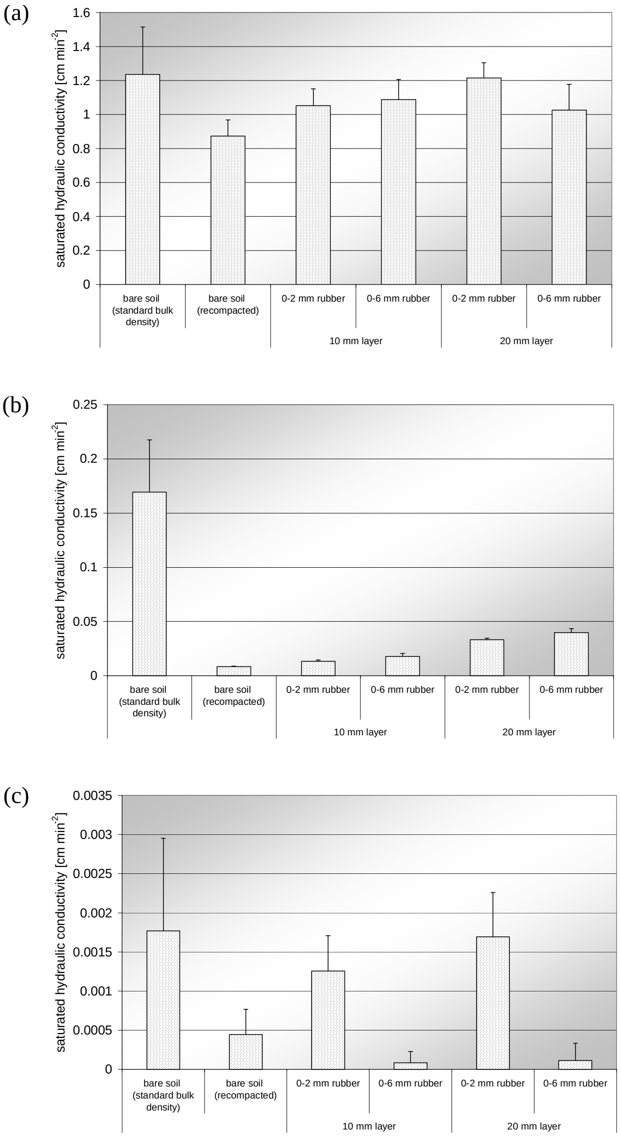

Figure 5.11 Effect of topdressing with crumb rubber on saturated hydraulic conductivity of underlying (a) loamy sand, (b) sandy clay loam and (c) light-medium clay

compared to the bare compacted treatment (Figure 5.11b). For this soil, increasing depth of topdressing maintained higher hydraulic conductivity with no significant difference due to the size of the crumb rubber used. However, for the clay soil, topdressing with 0-2 mm crumb rubber resulted in significantly greater saturated hydraulic conductivities than using the 0-6 mm crumb size (Figure 5.11c). There was no significant difference between the bare compacted clay and the clay topdressed at either 10 or 20 mm depth with the 0-6 mm crumbed rubber.

5.4 Discussion

Incorporation of Hydrocell flakes

The incorporation of the Hydrocell flakes produced no significant change in the water holding capacity for any of the soils. This is contrary to the claims of the supplier and may be due to the low internal strength of the flakes which appeared to compress under the compactive force applied. This is consistent with observations of Hydrocell injected into the non-irrigated Morningside training field (Henderson, *pers comm*.) and suggests that while Hydocell may increase moisture holding under uncompacted conditions (eg. loose soil in pots), it would not be expected to increase soil moisture holding capacity under normal compactive conditions experienced on sports fields. However, the incorporation of the Hydrocell produced a significant decrease in the penetration resistance (Table 5.3) and increase in the impact penetration depth (Figure 5.3) while creating only a marginal decrease in bulk density (Table 5.2). This suggests that the Hydrocell flakes may be acting like a lubricant in reduce the resistance to penetration. This may provide some benefit to assist in root penetration under field conditions. However, it seems likely that as the flakes dry out or age that the lubricant effect will deteriorate. Hence, further research would need to be conducted to evaluate the magnitude, longevity and potential agronomic benefit of this effect.

Use of biosolids

The incorporation of biosolids had no significant effect on penetration resistance or shear strength for any of the soils but significantly reduced the hardness of the surface as measured by deformation. The increase in deformation due to biosolids incorporation was greatest in lighter textured soils with significant increases also in the magnitude of rebound (difference between initial and long term deformation). This suggests that biosolids amended soils (particularly loamy sands) would be expected to feel softer and more "springy" under foot. Hence, incorporation of the biosolids should not adversely affect playability on sporting fields at the rate evaluated and may reduce injury rates.

The bulk density of the biosolid amended soil was reduced in proportion to the lower density of the applied organic material. However, incorporation of biosolids had a significant beneficial effect on the total porosity and moisture holding capacity irrespective of soil texture. The readily available water capacity between 8 and 33 kPa increased by approximately 1 % in the loamy sand, 3 % in the sandy clay loam and 7 % in the clay. Incorporating biosolids into the clay soil greatly increased the saturated hydraulic conductivity and the air-filled porosity under potentially waterlogged conditions (e.g. 4 kPa). However, the benefits were less obvious in the lighter textured soils with a slight reduction in hydraulic conductivity for both the loamy sand and sandy clay loam. These results suggest that incorporated biosolids should improve root zone conditions on sporting fields, particularly for clay based profiles.

The evaluation of biosolids as a topdressing material indicated that this product provides only a limited potential to reduce structural degradation of the underlying soil. The porosity and soil-water benefits noted above for incorporated biosolids would not be expected to occur where the product is topdressed.

It should also be noted that there was no evaluation of the nutritional benefits or degradation rates of the biosolid material used in this study. However, degradation would be expected to increase with increasing temperature, moisture and the presence of appropriate microbes. Hence, further research could be considered to evaluate the magnitude and longevity of agronomic benefits associated with incorporating biosolids under normal field conditions.

Topdressing with crumbed rubber

The application of crumbed rubber topdressing was found to substantially protect the underlying soil from subsequent compactive forces and improve agronomic conditions within the root zone. Penetration resistance of the soil underlying the topdressing was lower (e.g. Table 5.6) and soil softer as evidenced by larger depths of impact penetration (Figure 5.7). In general, the greater the depth of crumbed rubber applied to the surface the larger the benefits measured. The soil structural properties of total porosity, moisture holding and air-filled porosity were all significantly greater under crumbed rubber topdressing compared to a bare soil control treatment (Table 5.7). There was typically no difference in the agronomic or playability benefits observed between the 0-2 mm and 0-6 mm crumbed rubber products. However, the saturated hydraulic conductivity of the underlying clay soil was significantly greater under the 0-2 mm crumbed rubber compared to the 0-6 mm product (Figure 5.11c).

Deformation and rebound of the crumbed rubber surface increased with depth of topdressing (Figure 5.9). Topdressing with 20 mm of crumbed rubber was found to produce deformation values between 9-10 mm with rebound of approximately 7 mm (Figure 5.9). While these values were measured with an underlying sandy clay loam soil, they would not be expected to vary greatly with variations in underlying soil texture. Hence, topdressing with 20 mm of crumbed rubber would be expected to provide a softer surface than typically experienced on either sand based profiles or dry, compacted clay based profiles. Hence, crumbed rubber could be expected to reduce the risk of impact injuries experienced under bare soil conditions and may also be important in regard to watering of sporting fields during the playing season. With crumb rubber as a topdressing, there should be a reduced need to water prior to playing in an effort to reduce surface hardness. Removing or reducing this watering requirement would reduce the risk of compacting the underlying soil and maintain better growing conditions for the turf.

5.5 Conclusions

The effect on soil physical properties of incorporating or topdressing various different amendment products has been evaluated. The incorporation of Hydrocell flakes into the soil profile was not found to provide agronomic or playability improvements under the compacted conditions likely to be experienced on sporting fields. No further evaluates are recommended for this product. However, the incorporation of biosolids into the soil profile does appear to provide some agronomic and playability benefits. Agronomic benefits associated with improved soil-water capacity and internal drainage appear to be greatest on clay based profiles. It is recommended that further research into the longevity and magnitude of benefits associated with the incorporation of biosolids be conducted under field conditions.

Topdressing with crumbed rubber was found to be an effective strategy to protect the underlying soil structure from compactive forces likely to be experienced in the field. Biosolid topdressing produced only marginal protective benefits on the underlying soil. Crumbed rubber deformation measurements suggest that it is will typically provide a softer surface with greater rebound potential than existing soil based surfaces. These characteristics would be expected to reduce player injury risk. Hence, it is recommended that the agronomic and playability benefits of topdressing with crumbed rubber be evaluated under playing conditions.

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