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AN INVESTIGATION OF SELECTED SOIL PROPERTIES INFLUENCING THE MANAGEMENT AND PLAYABILITY OF NEW ZEALAND CRICKET PITCHES

A thesis presented in partial fulfilment of
the requirements for the degree of
Master of Horticultural Science in Soil Science
Massey University

Stuart Paul Cameron-Lee

1988

INTRODUCTORY SUMMARY

The 1980's has been a period of growth for New Zealand cricket. The advent of the one day game plus international success has developed spectator interest and support to an unprecedented level.

Cricket is certainly one game where player performance is very much dependent on the surface provided. It is perhaps fair to say that the standard of many New Zealand first class pitches has not allowed the development of entertaining cricket. As a result, pitches have been the target of increasing criticism from spectators, administrators, and players alike.

Cricket pitch preparation has been said to be an 'art'. But the groundsman has limited scope to practice the art if the suitability of the soil used for pitch preparation is wanting.

In an attempt to gain an understanding of the contribution of soil properties to good pitch preparation, the New Zealand Cricket Council and Soil Bureau of the Department of Scientific and Industrial Research (DSIR) provided funding for a research programme. It was hoped that improved playability and pitch performance could be achieved by combining the 'art' of pitch preparation with sound scientific principles.

The objectives of the research programme were:

1. To develop and standardise a set of laboratory procedures aimed at selecting soils and characterizing their suitability for cricket pitches.

2. To establish a comprehensive inventory of physical and chemical soil properties for a number of current pitch soils which can be used as a reference for selection of new pitch soils.

3. To relate sound scientific principles to field management techniques and pitch performance in an attempt to assist the groundsman with pitch preparation.

4. To investigate the contributions of management factors to pitch playability, and their interactions with soil properties.

5. To elucidate the value of the nuclear moisture-density method for in situ measurement of pitch soil water content and bulk density.

6. To develop and implement a soil monitoring system for groundsmen who can then use it to evaluate changes in soil properties during pitch preparation. This would allow the development of specific management programmes for individual venues.

7. To suggest areas for future research.

To meet these objectives a preliminary study (Cameron-Lee, 1984) was carried out to identify three soil parameters, namely clay content, clay type, and pitch soil profile, which affect pitch performance. An expansion of the findings of the preliminary study form the basis of this research programme.

This investigation incorporated a field trial using four soils commonly known as the Palmerston North[1], St John, Ward, and Kakanui. The soils have different chemical and physical properties. They are all currently in use throughout New Zealand on first class pitches. In addition, three pitch soils, namely the Marton, Redhill and Naike were evaluated, along with the field trial soils in the laboratory to provide a greater comparative analysis of pitch soil properties.

----

[1] A mixture of the Marton soil and unidentified local fine sandy loam.

The soils studied can be described as follows:

Pitch Soil	Soil Classification
1. Palmerston North[1]	
2. Marton	A central yellow grey earth described by Campbell (1979).
3. Kakanui	Known as the Waiareka clay, this soil is a southern brown granular clay (an intergrade between rendzina - like soil and brown granular clay) described by N.Z. Soil Bulletin 26 (3), (1968).
4. Ward	A central yellow grey earth described by N.Z. Soil Bureau Bulletin 27 (1968).
5. St John	No classification available.
6. Naike	A brown granular loam described by Bruce (1978).
7. Redhill	A Whatitiri clay loam (Red loam) hill soil described in N.Z. Soil Bureau Bulletin 5 (1954).

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[1] A mixture of the Marton soil and a local soil (unclassified).

The broad conclusions that can be drawn from this study are:

1. The interaction between clay type and clay content has a major influence on pitch performance.

2. For the preparation programmes used, swelling clay soils were found to be more difficult to manage and produced inferior playability results when compared to non swelling soils.

3. The performance ranking (from best to worst) of the trial soils used was consistently Palmerston North, St John, Ward and Kakanui.

4. The nature of the pitch profile construction was found to influence performance. For example, a shallow clay soil layer over a sand base produced significantly faster drying within the surface 75 mm.

5. Subsurface (25-75 mm) water content was the single most important factor that influenced pitch playability. Complex interactions, however, occur between water content, soil chemical and physical properties, and managment factors (e.g. the ability of the grass plant to remove water from depth) and these contribute to the performance of the pitch soil.

6. Soil properties characterize the potential of a pitch soil but pitch management determines the development of that potential.

7. Soil binding strength which is commonly used as a guide to pitch soil selection may not necessarily be a reliable index of soil performance. A standardised testing procedure was developed for pitch soil selection.

8. In order to guide groundsmen during pitch preparation, standard monitoring techniques have been developed.

The study identified areas for future research. These include:

1. A study of the influence of different levels of soil compaction (bulk density) on the water retention characteristics (field capacity; stress point; permanent wilting point) of pitch soils.

2. A more comprehensive study of plant-soil interactions to quantitatively determine the role of the grass plant in pitch soil drying and performance of the cricket pitch.

3. An investigation of different mowing management programmes on the rate and extent of pitch soil water loss.

4. A study of the use and effects of different physical treatments during pitch renovation.

5. A study of the modification of swelling soils with compatible non swelling types to moderate undesirable soil properties and improve management and playability.

6. An investigation of the design of pitch soil irrigation systems for different levels of cricket.

7. An investigation of the feasibility for greenhouse structures at Test venues.

8. An evaluation and calibration of the Clegg impact hammer for replacement of the bounce test as the objective method of playability assessment for New Zealand pitch soils.

9. The development of a standardized soil monitoring kit for use by groundsmen at venues throughout New Zealand.

10. Ongoing investigation and evaluation of potential pitch soils for improvement of existing soils and pitches.

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TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF PLATES

Page

LIST OF EQUATIONS

LIST OF APPENDICES

CHAPTER 1: REVIEW OF LITERATURE

1.1 Desirable Pitch Characteristics

For a first class match the cricket pitch should ideally exhibit a number of desirable characteristics.

(i) Players' Requirements

1. The pitch must have pace early in the match.

2. Movement of the new ball must not be due to excessive grass or a high pitch soil moisture content.

3. There should be a slight advantage for the seam bowler in that there is 'the opportunity to put a little in, and get a little out'.

4. The ball bounce must be even.

5. The pitch should gradually dry out and by day four the ball should be starting to 'grip' a little for the spinner, yet still retain its pace.

6. The ball should never go through the surface of the pitch at any stage of the match.

(Adapted from Parker 1982; Turner, 1986).

(ii) Soil Requirements

1. Soil plasticity should be sufficient to allow remoulding and compaction by rolling, and to provide a smooth surface.

2. Soil consistence should provide vertical stability, preventing differential change in elevation of parts of the surface, lifting out of soil, crumbling or powdering.

3. The surface should be hard and smooth so the elasticity of the ball is manifested and the pace of the ball is not significantly reduced on impact with the pitch.

4. The level of fertility must be adequate to support a complete grass cover prior to final preparation.

5. It is desirable that the soil has an ability to recover from any adverse effects caused by compaction during soil preparation. The soil structure and turfgrass should be regenerative, such as with a cracking soil.

6. There should not be excessive cracking or excessively wide cracks.

7. The soil must have sufficiently high permeability when wet, to ensure reasonable rates of water movement and leaching of salts through the profile.

8. There needs to be some means for removal of excess water so that soil aeration can occur.

(Adapted from McIntyre, 1983a)

1.2 Methods for Measuring Pitch Performance

(i) The Bounce Test

Player assessment of cricket pitch pace is subjective and can be variable. Stewart and Adams (1969), carried out a comprehensive cricket pitch research study aimed at devising objective methods for assessing pitch pace. They set out to determine those features of the soil and its management which influence pitch pace.

To assess potential pace of the pitch, they developed the bounce test. Rebound bounce height of a cricket ball dropped vertically on to the pitch from 4.9 metres (16 feet) was measured. (Bounce heights recorded were those of the top of the ball). They concluded that bounce from a vertical drop was little affected by the thin grass cover left on a prepared pitch or by the minute changes in surface roughness from variations in soil texture. The range of individual values recorded was used to provide evidence of:

(a) Uniformity of bounce
(b) Any variation in bounce between pitch ends
(c) The maximum pace developed.

Stewart and Adams (1969), used a scale to relate bounce and pace. (Table 1.1).

Dury (1978), found the bounce test to be highly satisfactory for grass cricket pitches, and its use on a number of pitches enabled him to conclude that the 'stronger' the soil, the higher the bounce and the faster the pitch. Dury observed that lower grade pitches in England exhibiting bounce tests greater than 45 cm were characterised by use of a heavy roller and a clay soil.

Dury (1982), reviewed developments made with the bounce test. The original 4.9 metre drop height was difficult to work from and prone to eccentric ball delivery. A more convenient ball drop height of 3 metres was adopted and rebound bounce expressed in percentage terms as follows:

$$\text{Rebound bounce (\%)} = \frac{\text{Rebound Height}}{\text{Drop Height}} \times 100\ \% \qquad [1.1]$$

Stewart and Adams' scale was converted to percentage terms (Table 1.2).

TABLE 1.1 Relationship of rebound bounce to pitch pace.

Bounce	Pitch Pace
Over 76 cm (30 in)	Very fast
64-76 cm (25-30 in)	Fast
51-64 cm (20-25 in)	Moderately fast
38-51 cm (15-20 in)	Easy paced
Less than 38 cm (15 in)	Slow

(Adapted from Stewart and Adams, 1969)

TABLE 1.2 Relationship of ball rebound bounce, expressed in percentage terms, to pitch pace.

Percentage	Pitch Pace
Over 15.6%	Very fast
13-15.6%	Fast
10-13%	Medium-easy paced
8-10%	Slow
0-8%	Very Slow

(Dury, 1982)

Murphy (1984), discussed the results of a pitch playability survey undertaken throughout New Zealand during the 1983/84 season. Playability of pitches was assessed subjectively by players and umpires and objectively by the bounce test. Murphy found that the bounce test results could be related to four categories of pitch pace (Table 1.3).

Most pitches studied were in the slow to easy paced category. In general, the pitches unsuitable for cricket fell within the slow and very slow categories. Acceptable pitches also showed a low variation with the bounce test (Murphy, 1984). Murphy (1985), found that there was a very close relationship between bounce test variation and subjective assessment of bounce consistency.

(ii) The Terry Keeling (T.K.) Pitch Tester

Dury (1982), introduced a development to assess pitch playability. The T.K. Pitch Tester was developed to simulate the bounce of the ball on a pitch during play. A ball was projected from the tester onto a predetermined area of the pitch and both the point of impact with the pitch and the bounce height were recorded. The design and positioning of the tester produced a similar trajectory of ball delivery to the average medium-paced bowler (Dury, 1978). Although it was stated that useful information has been generated using the T.K. Pitch Tester, no results were published.

(iii) The Friction Test

Murphy (1986), stated that while a major proportion of the research undertaken in England has been concerned with the bounce test, pitch pace is not determined by bounce alone. Movement in the horizontal plane, representing the pace at which the ball comes onto the bat, and in the lateral plane, representing sideways movement off the pitch, are also important. To measure the influence of these factors, a friction test was developed by Murphy. The test involved measuring the force required to move a sledge and series of weights on the surface of the pitch. Murphy proposed that the higher the

TABLE 1.3 Relationship of ball rebound bounce to pitch pace for New Zealand pitches.

Bounce (cm)		Pitch Pace
Average	Range	
77	-	Fast
69	62-72	Easy paced to fast
60	50-70	Easy paced
49	44-54	Slow to easy paced
45	44-47	Very slow to slow
44	-	Very slow

(Murphy, 1985)

TABLE 1.4 Pitch pace rating scale

Pace Rating	Pitch Pace
0-50	Very slow
50-100	Slow
100-300	Easy
> 300	Fast

(Murphy, 1986)

friction the more sideways movement, and also the slower the forward pace of the ball. The bounce and friction tests were incorporated by Murphy into an overall pace rating scale:

$$\text{Pace rating} = \frac{\text{Ball bounce}}{\text{Friction}} \qquad [1.2]$$

During the 1984/85 and 1985/86 seasons, pitches in New Zealand were assessed by this objective playability method. A pace rating scale was developed (Table 1.4).

Murphy (1986), found that a good relationship existed between pace rating and subjective assessment of pitch pace. In general, the bounce test on the third day of a match was higher than on the first day, but the pitch was generally slower on the third day. This was due to the pitch surface being rougher on the third day as a result of surface crumbling and wear, thereby causing the pitch to have greater friction or resistance to the ball. The greater the surface friction the greater the potential for the pitch to take spin (Murphy, 1985). As a result of this study, Murphy outlined recommendations for standards of playing characteristics for one-day, three-day and five-day pitches (Table 1.5).

(iv) The Adams Stewart Soil Binding Test (A.S.S.B. Test)

Stewart and Adams (1968), addressed the importance of soil binding strength. To establish the precise significance of soil texture on soil strength they developed the Adams Stewart Soil Binding Test (A.S.S.B. test). The test involved wetting, moulding and drying spheres of soil (motties) approximately 20 mm in diameter and measuring the force required to shatter them when compressed. In developing this strength test they attempted to parallel the sequence of events a groundsman should follow when preparing a cricket pitch (Stewart, 1985). From this work, Stewart and Adams developed the following set of standards:

TABLE 1.5 Standards of playing characteristics for New Zealand first class pitches.

Match day	1 Day		3 Day		5 Day	
	Duration of Match					
	Bounce (cm)	Friction	Bounce (cm)	Friction	Bounce (cm)	Friction
1	> 65	< 0.2	> 60	0.4	> 65	0.4-0.5
2				0.2		-
3				0.2-0.3		0.2
4						-
5						0.2-0.3

(Adapted from Murphy, 1986)

1. Soils which disintegrate at a pressure up to 45 kg (100 lbs) are not suitable for use on a cricket pitch.

2. Soils which disintegrate between 45-70 kg (100-150 lbs) are suitable for club pitch use.

3. Soils which disintegrate between 70-90 kg (150-200 lbs) are suitable for county and international pitch use.

4. Soils which disintegrate at pressures greater than 90 kg (200 lbs) tend to be too strong for cricket pitch use.

(Adapted from Dury, 1982)

When developing this test, Stewart and Adams found that the strength value derived for individual soils was significantly influenced by the operator. In effect, the person undertaking the A.S.S.B. test significantly influenced the soil strength value recorded.

Other factors thought to influence soil strength and which are measurable in the laboratory include soil organic matter content, clay type, and the degree to which the individual clay particles are dispersed (Stewart and Adams, 1968).

Stewart and Adams noted that binding strength values based on the A.S.S.B. test correlated well with bounce heights measured on county pitches, despite variations caused by weather conditions and wear. It was proposed that this technique could provide a method for predicting the effect on pace of soil materials proposed for use in topdressing pitches (Stewart and Adams, 1968).

The relationship between A.S.S.B. rating and bounce is as follows:

$$\text{Bounce height (inches)} = 0.1 \times \text{A.S.S.B. rating} + 9.0 \qquad [1.3]$$

McIntyre (1984b), noted that the A.S.S.B. test was developed on non swelling soils, which are light clay or clay loams (30-40% clay). He suggested that the A.S.S.B. test is invalid for swelling soils because it is too insensitive to the rate and manner of motty drying. McIntyre postulated that incipient micro-cracks would almost certainly develop in swelling type soils which shrink on drying. The presence of such cracks would affect the measured compressive strength.

Murphy (1985), found that the majority of soils used on first class pitches in New Zealand had breaking strengths of 70-90 kgs i.e. suitable for county and international pitch use. One venue with an A.S.S.B. test value of less than 20 kg continually produced unacceptable pitches. The venues with A.S.S.B. test value between 40-50 kgs were consistently easy paced and had a good record for producing quality pitches. Soils with an A.S.S.B. test value greater than 100 kg produced acceptable pitches, although little spin was evident during these matches.

A recent modification to the motty test, is described by Adams (1987). This modification of the A.S.S.B. test enabled the determination of soil suitability for topdressing of cricket pitches. Adams stated that the most common cause of unsatisfactory county cricket pitches is the use by groundsmen of soils for topdressing which are incompatible with the native soil on the square. Layering develops, horizontal growth of roots between layers results, and binding fails. This leads to surface break up and unpredictable bounce. Adams was of the opinion that the shrinking and swelling capacity of different soils was the most likely property determining compatibility. He concluded that in general, the magnitude of this property increased with clay content but the type of clay and organic matter content were also important factors.

The method involved making motties as in the A.S.S.B. test but composed of 50:50 mixtures of the two soils being tested. It was evident that similarity in clay content was not necessarily a good indication of compatibility between soils. Adams stated that complex factors affect compatibility of soils, and it is difficult to make predictions based on analytical data. While he did not outline these complex factors, it was concluded that modification of the A.S.S.B. test could be used to provide direct information about soil compatibility.

(v) Clegg Impact Hammer

In the Impact test, a fixed weight is dropped from a predetermined height onto the test surface and an accelerometer measures the deceleration of the weight at impact. This provides a measure of the resistance to surface deformation (i.e. hardness). The harder the surface the higher the impact value (Lush, 1985).

Lush (1985), discussed the objective assessment of cricket pitches by the Clegg hammer. Impact results were consistent with ball behaviour and soil properties, and the correlation between impact values and ball rebound height was statistically significant. Lush proposed that the impact hammer could be used to predict pitch pace and measure pitch variability during a match. Further, the impact hammer is inexpensive, portable, quick to use and can be operated by one person.

1.3 Factors Affecting Pitch Performance

(i) Clay Type

The clay fraction of soils seldom contains one clay mineral, but more usually consists of several clay minerals which may be:

- crystalline minerals (give a diffraction pattern when irradiated with X-rays) or
- short-range order materials (amorphous to X-rays).

(a) Structure of Crystalline Clay Minerals

Crystalline clay minerals are composed of two fundamental units. A tetrahedral unit consists of a silicon ion around which four oxygen ions are arranged in close packing (Figure 1.1a). When linked together through basal oxygen ions, the tetrahedra form a sheet (Figure 1.1b). The second fundamental unit is the aluminium octahedron which consists of six hydroxyl groups closely packed, the hole in the centre being occupied by an aluminium ion (Figure 1.2a). When linked together through hydroxyls, a sheet is formed (Figure 1.2b).

1:1 Structure (e.g. Kaolinite, Halloysite)

One sheet of tetrahedral units is condensed with one sheet of octahedral units, and the resulting layer is stacked upon like layers. Between layers, oxygen ions faces hydroxyl groups and the resulting hydrogen bonds are strong (Figure 1.3). This strong hydrogen bonding prevents ready separation of layers, thus there are no water molecules or cations in the interlayer space. The lattice is therefore said to be non-expanding and there is no tendency for soils containing these crystalline minerals to swell on wetting and shrink on drying (Thompson and Troeh, 1978).

All the cation sites within the tetrahedral part of the layer are occupied by Si^{4+} ions, and generally, there is little or no isomorphous substitution of Si^{4+}. Electrical neutrality of the crystal lattice is preserved when one-third of the cation sites in the octahedral portion of the layer are empty i.e. only two out of three sites are occupied by Al^{3+}. The mineral is said to be dioctahedral. Examples of dioctahedral 1:1 minerals include kaolinite and halloysite.

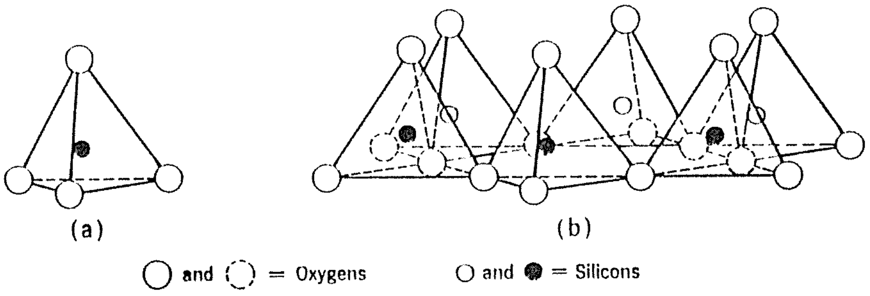

Figure 1.1 Diagrammatic sketch showing (a) a single silicon tetrahedron and (b) the sheet structure of silicon tetrahedra (Grim, 1968).

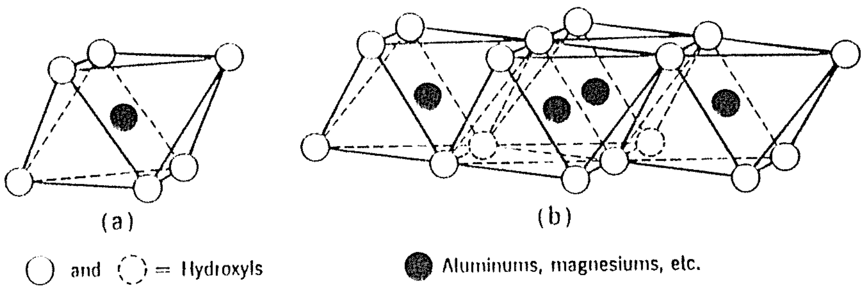

Figure 1.2 Diagrammatic sketch showing (a) a single octahedral unit and (b) the sheet structure of aluminium octahedra (Grim, 1968).

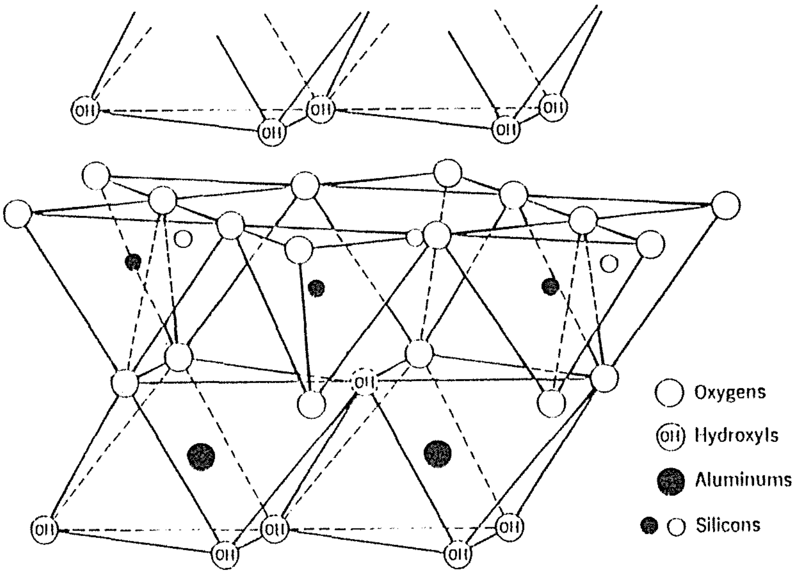

Figure 1.3 Diagrammatic sketch of the structure of the kaolinite layer (Grim, 1968).

Although these structures are electrically neutral (Theng, 1984), during the course of crystallisation a small proportion of the Al^{3+} ions may be isomorphously replaced by ions of lower valency (e.g. Fe^{2+}), and consequently the lattice overall carries a small negative charge. This charge contributes to the cation exchange capacity (CEC) of the clay, and is neutralised by cations from the soil solution.

Kaolinite crystals are pseudo-hexagonal in shape. They range in size from 1.0-2.0 µm across (Table 2.2). The restricted specific surface area and limited adsorptive capacity for cations and water molecules suggest that kaolinite does not exhibit such properties as shrinkage and swelling and cohesion to an appreciable degree.

Halloysite has a similar structure to kaolinite but contains sheets of interlayer water which are trapped during crystallisation. Although collapse of the structure can be induced by gentle heating in the laboratory, it is improbable that collapse occurs in the field. The high humidity present in the soil pore network is sufficient to prevent dehydration of halloysite.

The presence of water between the layers alters the distribution of stresses within the mineral lattice such that the layers curve to form a tubular structure (White, 1987).

The somewhat greater specific surface area of halloysite means that colloidal properties are exhibited rather more strongly than in kaolinite (Brady, 1984).

2:1 Structure (e.g. Mica, Vermiculite, Smectite)

Structure of the 2:1 clay minerals characterised by one octahedral sheet condensed between two tetrahedral sheets (Brady, 1984).

Mica: The common micas are muscovite (white mica), which is dioctahedral, and biotite (black mica) which is trioctahedral. In muscovite, two-thirds of the octahedral positions are occupied by Al^{3+} ions, while in biotite all octahedral positions contain Mg^{2+} and Fe^{2+} ions. For both minerals, during crystallisation about 25% of Si^{4+} ions are replaced by Al^{3+} ions, and a net negative charge develops on the lattice. Part of this charge is neutralised by K^{+} ions located between the layers (Figure 1.4). The potassium ions fit snugly into holes in the tetrahedral sheets (Thompson and Troeh, 1978), and serve to tightly bind the layers together. Since K^{+} ions are tightly trapped between the layers, they cannot migrate easily to the soil solution, and are therefore non-exchangeable. The remainder of the negative charge (which contributes to CEC) is neutralised by cations from the soil solution.

While the unweathered lattice is quite non expansive, slight to moderate swelling and shrinkage can occur with changes in water content as the mineral weathers. Expansibility depends upon how many of the planes of potassium ions have been weathered out.

Crystal size is intermediate between that of smectite and kaolinite, commonly between 0.1.0 μm (Table 2.2. Properties such as hydration, cation adsorption, swelling, shrinkage, and cohesion are less strongly expressed than for smectites, but they do exceed those of kaolinite.

Vermiculite: Vermiculite commonly form as a result of weathering and chemical alteration of mica materials, and thus may be either dioctahedral or trioctahedral. When weathering of micas takes place at pH values 5.5 to 7.0, magnesium enters the interlayer space to form vermiculite. When weathering occurs at pH values less than 5.5, aluminium being the dominant cation in the soil solution, enters the lattice to give an aluminium vermiculite. Many vermiculites have a mixture of aluminium and magnesium ions in the interlayer space.

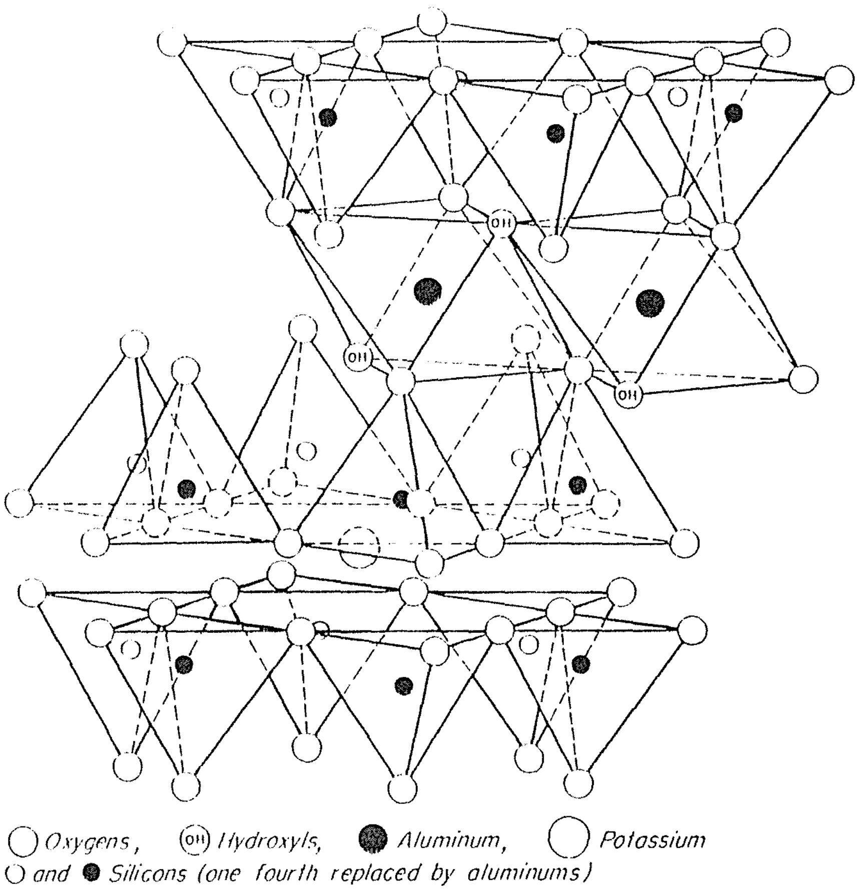

Figure 1.4 Diagrammatic sketch of the structure of muscovite (Grim, 1968).

In vermiculite, the 2:1 layers are stacked atop each other as for mica, but water molecules linked together in a hexagonal net formation containing entrained magnesium ions, separate the layers. These magnesium ions are exchangeable with ions in the soil solution. Although the water molecules, together with magnesium ions, are strongly adsorbed in the interlayer space, they act more as bridges holding the layers together than as wedges driving them apart. Since the degree of shrinking and swelling is considerably less than for smectite, vermiculite is considered to have a limited expanding lattice with some effective internal surface area (Brady, 1984).

In the tetrahedral sheet of vermiculite, up to 25% of the Si^{4+} ions are replaced by Al^{3+} ions. This accounts for most of the excess net negative charge which is partly neutralised by magnesium ions in the interlayer space. Most of the excess negative charge is neutralised by ions from the soil solution, accounting for the high cation exchange capacity of vermiculite.

The size of vermiculite crystals varies, depending on the size of mica flakes from which they have been weathered, but they are usually intermediate in size between those of kaolinite and smectite.

Smectite: The interlayer positions in smectite are occupied by a variety of cations, including Mg^{2+}, Ca^{2+} and K^{+}, together with organic ions and water molecules. These cations are freely exchangeable with those in the soil solution. In the interlayer space, oxygen ions of one layer face oxygen ions of the next layer (Figure 1.5). Layers are loosely held together by very weak oxygen-to-oxygen and cation-to-oxygen linkages (Brady, 1984). The very weak hydrogen bonding enables water molecules and hydrated cations to move between the easily separated layers to produce an expanding lattice. As a result, soils containing such minerals shrink and swell appreciably with changes in moisture content.

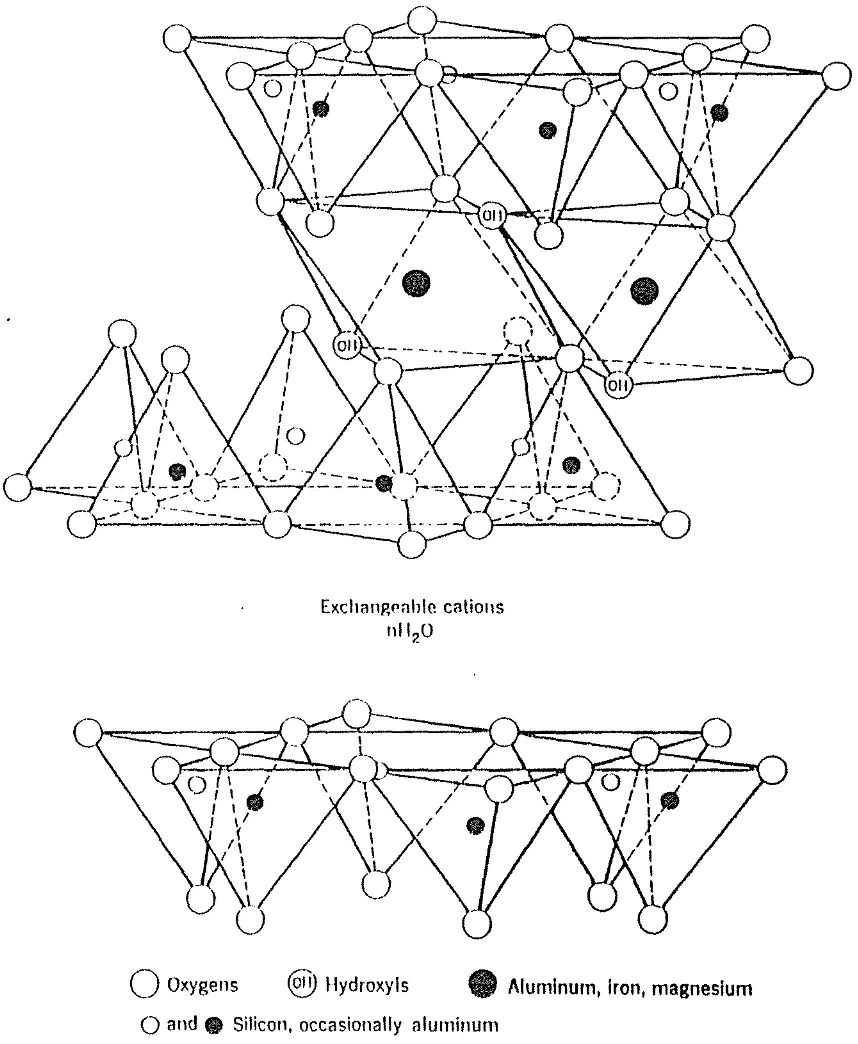

Figure 1.5 Diagrammatic sketch of the structure of smectite (Grim, 1968).

The CEC of smectites can be quite high due to up to 15% of Si^{4+} ions being replaced by Al^{3+} ions in the tetrahedral sheet, and by Al^{3+} ions in the octahedral sheet being replaced by varying amounts of Fe^{2+} and Mg^{2+} ions. This isomorphous substitution results in a high net negative charge and thus a high cation exchange capacity (Brady, 1984).

Separation of smectite layers gives particles with a thickness approaching that of single layers. Commonly they are less than 0.2 µm (Table 2.2). The large specific surface area and adsorptive capacity for cations and water molecules suggests that smectites have well-developed colloidal properties.

(b) **Short-range Order Materials**

Short-range order materials in soils constitute that fraction of the mineral assemblage which is amorphous to X-rays.

The principal short-range order inorganic materials in soils are oxyhydroxides of silicon, aluminium and iron together with small amounts of oxyhydroxides of manganese.

Iron hydroxide gels are ubiquitous to soils to which they impart yellow, brown and red colours. They may be present as coatings on soil particles, in which capacity they often act as cements binding textural particles into structural units, thereby conferring improved structural stability of soil in the field.

(c) **Clay Minerals and the Cricket Pitch**

<u>The Importance of Clay Type - An Introduction</u>

The importance and contribution of clays to the cricket pitch soil has been recognised for many years. Harris (1961), proposed that the clays used on Australian cricket pitches need to be of the smectite type to give the pitch a plastic consistency when wet, so that it can be compacted by heavy rolling to a dense form which will retain a massive structure upon drying. The dry clay provides a hard, brick-like footing, upon which the ball bounces truly and at an acceptable height.

Stewart and Adams (1968), recognised the importance of clay type and noted that clay particles differ significantly in their size, form and behaviour. Although their work suggested the influence of clay type should not be ignored, it was not investigated in this paper.

More recently, McIntyre (1983a) addressed the importance of smectitic clays to Australian cricket pitches. McIntyre stated that, in the absence of vermiculite, the soils which have the greatest cation exchange capacity and amount of swelling per unit clay, contain the most smectite. As smectitic soils are characterised by large volume changes with changes in water content, they swell on wetting and shrink on drying to crack into blocks of roughly cubical but relatively large size.

A high smectite, clay-rich soil can only realise its natural hardness and resilience if dried thoroughly and uniformly to depth by transpiration of grass (McIntyre, 1983b, 1984a). By nature of the inherent properties which cause them to shrink on drying, the swelling type clays provide a denser matrix than do the non swelling types (McIntyre, 1984a).

Lush *et al.* (1985), stated that soils in which the main clay minerals are hydrous mica or kaolinite are less hard when dry than smectitic soils and are more likely to powder or crumble during play. They also shrink less on drying. English pitch soils have a high kaolinite and hydrous mica content.

Cameron-Lee (1984), determined the dominant and minor clay minerals in a number of New Zealand pitch soils and found that most contain non-swelling type minerals. Murphy (1984), showed that pitches containing such clay minerals were faster paced and harder and also had lower moisture contents. He also showed that pitches with swelling type clay minerals played only slowly and low and had higher moisture contents. On the Eden Park pitch in Auckland, drying of the smectite soil resulted in the formation of unstable blocks which gave rise to inconsistent bounce. To reduce the extent of cracking and bounce inconsistency, the groundsman maintained the soil water content at a high level. This resulted in a slow pitch with low bounce. Murphy postulated that a cycle of events was established which is not conducive to producing a pitch of acceptable standard. Cameron-Lee (1984), stated that perhaps the lower moisture content of the non swelling soils was a reflection of management practices as well as clay mineral content. As soils containing these clay minerals crack only slightly, if at all, on drying, the groundsman may be prepared to reduce the moisture content of the soil to a much lower level before play. The result is a faster pitch with higher bounce.

(d) **Cracking and Playability**

McIntyre (1984a), noted that throughout New Zealand there appeared to be a mistrust by groundsmen of cracks greater than 5 mm. The crack width depends on the size of the units between cracks. If the unit is too small, narrow cracks result, which can cause soil crumbling. Units which are too large give rise to excessively wide cracks (McIntyre, 1984a; 1984b). McIntyre (1984b), also suggested that a suitable soil would have cracks around 5-8 mm width when dry. The network of primary and secondary cracks developed on drying of a smectite soil have no noticeable effect on bounce, provided they are not wider than 10-15 mm, and the soil surfaces between cracks remain level and firmly anchored.

Where substantial cracks occur, they are sometimes filled with soil by the groundsman. McIntyre (1984b), discovered that when such a pitch is thoroughly watered, filled cracks can distort as a result of lateral swelling of the whole pitch. Furthermore, it may not be possible to completely smooth out the distortion by subsequent rolling in preparation for a later match. McIntyre considered this practice to be undesirable.

McIntyre (1984b), proposed that because most New Zealand pitches are constructed from non swelling soils, groundsmen are suspicious of cracks and, hence, when a pitch is being prepared on a soil that cracks, a high moisture content is maintained to alleviate the problem. Unfortunately, the high moisture content regime adopted for such soils does not permit sufficient drying before play and the pitch plays only slowly and with low bounce.

(e) **Cracking and Regeneration of Structure**

Smectitic clay soils are characterised by the presence of substantial cracks when thoroughly dry (McIntyre, 1983a). The shrinkage upon drying has important practical implications. Most of the swelling smectitic soils have a structure in which the soil peds are separated by microcracks. Pitch preparation on such heavy clay soils results in soil compaction, which is detrimental to water and air movement in the soil, and ultimately turfgrass growth. Therefore, shrinkage upon drying is essential to promote cracking, thereby allowing rapid entry of air and water to root depth to aid grass rejuvenation after a match. Moreover, repeated shrinking and swelling regenerates structure, which improves the recovery of the grass plant (McIntyre, 1983b). In comparison, non swelling clay soils, once compacted, require mechanical manipulation to ensure a more favourable physical environment for the turf grass plant (McIntyre, 1984a).

(f) Water-holding Capacity and Water Movement

Clay type can influence the water-holding capacity of a pitch soil both indirectly and directly. Indirectly, the very small particles of smectite may be packed tightly together and have room for only a thin film of water around them. Much of this water is held so tightly by the large specific surface area of smectite that it is unavailable to the grass plant (Thompson and Troeh, 1978). Clay type can also directly influence a soils' water-holding capacity through the ability of some clay minerals to expand and absorb water internally e.g. smectite. Clay particle size is also important. For example, kaolinite particles are much coarser than smectite particles (Table 2.2). As a result of a smaller specific surface, kaolinite particles hold less water than smectite particles (Sopher and Baird, 1978). It follows, therefore, that the swelling type soils hold considerably more water between the plastic mouldable state and hardness resulting from drying, than do the non swelling soils for a similar matric potential. McIntyre (1984a) stated that the matrix (soil between vertical, air-filled cracks) of swelling clays is at all times saturated with water until it approaches the air dry condition.

At moisture contents for which the visible cracks of a swelling soil are closed, the microcracks are the main conductors of water. Pores within the soil peds are very small and water movement through them is slow. Thus, at the highest moisture contents, water movement is essentially reduced to zero unless macropores of biological origin exist (McIntyre and Sleeman, 1982). Unless structure regeneration to alleviate compaction occurs, the size, number and continuity of soil pores will preclude a fast rate of water movement through the profile. Therefore, sufficient time should be allowed between last watering and play to permit pitch soils to dry sufficiently and realise their potential to become hard when dried deeply and evenly.

(g) Soil Consistence

Soil consistence is a measure of soil workability, and is expressed in terms of the resistance the soil offers to deformation or rupture when subjected to a compressing, shearing, or pulling force. Consistence is the manifestation of cohesive and adhesive properties. Consistence is determined not only by the clay content and type of clay minerals present, but also by the structural state, the organic matter content, and the water content of the soil.

Depending on the water content, consistence may be expressed in terms of hardness or firmness when the soil is dry, and plasticity or stickiness when it is wet (Thompson and Troeh, 1978). Plasticity is the capacity of the soil to be moulded when wet in response to a stress, and to keep that shape when the stress is removed (Brady, 1984). Stickiness is manifested when the soil is wetted beyond the plastic state, and is a measure of the tendency of a soil to adhere to other objects (Thompson and Troeh, 1978).

Plasticity exhibited by clays is due to the plate-like nature of the particles and the lubrication conferred by adsorbed water. Hydrogen bonding between clay particle surfaces and water and between water molecules is the attractive force responsible for cohesion.

The degree to which these characteristics are expressed varies between different clay minerals. For example, the non-expanding clay mineral, kaolinite, normally occurs as relatively large pseudo-hexagonal plates with relatively low specific surface (Table 2.2). Cohesion, therefore, is not strongly expressed, and this limits the plasticity and stickiness of kaolinite as well as the ability of the mineral to form a hard surface on drying.

In contrast, such properties are strongly expressed by smectite. The very small particles have a much higher specific surface area (Table 2.2), allowing extensive contact with each other, which results in a high level of cohesion.

With regard to the cricket pitch, there must be sufficient soil cohesion to provide vertical stability in the soil profile and thus prevent differential change in elevation of the surface, lifting out of clods, and crumbling and powdering. Soil plasticity must be such that remoulding, compaction and a smooth surface can be achieved by rolling. The aim should be to produce a hard surface when the soil dries, so that elasticity of the ball is manifested and an acceptable bounce is produced (McIntyre, 1983a).

(ii) Exchangeable Cations and Soil pH

(a) **Cation adsorption and exchange**

Colloidal soil particles generally carry a net negative charge. This negative charge can arise in two ways:

1. Permanent charge arising from substitution of cations of similar size but lower valency within the crystal lattice of aluminosilicates e.g. Mg^{2+} for Al^{3+}. The development of permanent charge is discussed for individual clay minerals in Section 1.3 (i).

2. pH dependent charge arising from reversible dissociation of H^{+} ions from surface carboxyl or phenolic groups in organic polymers, or at SiO^{-} or Al(OH) polymer sites on the surfaces of oxides and edge faces of clay minerals. The degree of dissociation of these groups is dependent on their acid strength and the activity of H^{+} ions in the ambient solution.

The sum of permanent and pH dependent charges is usually measured as the cation exchange capacity (CEC). Cation exchange capacity represents the ability of a soil colloid to hold cations and yet allow their ready exchange with those in the soil solution.

Micaceous clays have a high permanent charge, but a relatively low cation exchange capacity due to much of the permanent charge being neutralised by interlayer K^+ ions. In vermiculite, Mg^{2+} ions occupying the interlayer space are more readily exchangeable with other cations in the soil solution, and accordingly the net negative charge is much higher than that of mica. As there is little isomorphous substitution in kaolinites, the permanent charge is small and the bulk of cation exchange capacity is pH dependent. Conversely, for smectites the bulk of the cation exchange capacity is attributable to the permanent negative charge, and the pH dependent charge is less important. The relative contribution of pH dependent and permanent charges to the CEC of any one mineral group depends on the edge:planar face ratio of the clay crystals. Large ratios mean a greater contribution of pH dependent charge to CEC.

The measured CEC of soil is dependent on the nature of the replacing cation employed, the concentration of the salt and the equilibrium pH. In addition, the CEC of a soil depends not only on the components of the clay fraction, but also on the amount of clay present and the nature and amounts of organic matter. Organic matter is very important in modifying the effect of clay minerals. For example, if a soil with 25% clay content possesses as little as 3% organic matter, then at pH 7 the soil organic matter would account for nearly 40% of the CEC of the soil. This occurs because humic substances of organic matter have a large specific surface (1000 m^2/g) as compared with the soil mineral components (kaolinite, 15 m^2/g; smectite 770 m^2/g). As the amount and nature of soil organic matter differs considerably depending on soil type, climatic conditions, and season, the contribution of organic matter to CEC is variable (Mengel and Kirkby, 1987). The mechanism of cation adsorption and the principles of cation exchange processes are described by Mengel and Kirkby (1987).

Numerous cations including calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), ammonium (NH_4^{+}), aluminium (Al^{3+}), iron (Fe^{2+}/Fe^{3+}), and hydrogen (H^{+}) are adsorbed on the soil exchange sites. A knowledge of the amounts and kinds of exchangeable cations provides information about soil chemical properties, including soil fertility and pH. Adsorbed cations also influence soil physical properties (Tisdale and Nelson, 1975).

(b) Exchangeable Cations and Fertility

The cations adsorbed on exchange sites can be divided into two groups. The basic cations include calcium, magnesium, potassium, and sodium. Hydrogen and aluminium ions are associated with acid soil conditions.

The base saturation is the percentage of total CEC occupied by basic cations, and is related to soil pH and the level of soil fertility. For a soil of any given organic matter and mineral composition, the pH and plant availability of basic cations will increase with an increase in base saturation. The relationship between base saturation and cation availability is also modified by the nature of the organic matter and clay mineral fractions.

(c) Exchangeable Cations and Soils Physical Condition

While soil texture is very important in determining the soil physical behaviour, soil behaviour is also closely related to the nature and availability of exchangeable cations.

Soil structure may be defined as the arrangement of soil particles into aggregates (Brady, 1984). The stability of soil aggregates depends largely on the cations adsorbed to the soil colloids. Poor structure occurs where Na^+ or K^+ are dominant on the exchange complex, as they have a dispersing effect (Mengel and Kirkby, 1987). This causes aggregate breakdown and reduced permeability of the soil to water, air, and root movement. Dispersion also results in the formation of dense, impenetrable surface crusts which may hinder the emergence of turfgrass seedlings on germination after renovation. Furthermore, as the exchangeable sodium percentage (ESP) increases, the hydraulic conductivity of the soil generally decreases. McIntyre (1983a), reported it preferable to have an ESP less than 5, and ideally below 3.

Divalent cations such as Mg^{2+} and Ca^{2+} are very effective in bringing about flocculation, and contribute to the formation of stable soil aggregates (Mengel and Kirkby, 1987). In combination with humic acids and clay minerals, Ca^{2+} also forms stable organo-mineral complexes (Schachtschabel, 1967).

But although a well-aggregated soil will ensure good physical conditions for turf growth, it may be difficult to compact and bind into a sufficiently coherent mass to provide the solid brick-like footing needed for a pitch. Further, a clay which flocculates to produce aggregates is likely to present wear problems, with the surface prone to crumbling upon drying. Such crumbling soils are often classed as self mulching, and are often characterised by high Ca^{2+} levels. Pitch soils are, therefore, selected from well-dispersed clay soils which can be readily compacted by rolling.

(d) **Soil pH**

Soil pH is a measure of soil acidity or alkalinity, and it influences chemical, physical, and biological soil properties (Rieke, 1969).

The most universal effect of pH on plant growth is nutritional. Soil pH influences the rate of plant nutrient release from minerals by weathering, the solubility of all soil materials, and the amounts of cations stored on exchange sites.

The distribution of exchangeable cations on the exchange sites and the interactions occurring between cation species in the soil have an important effect on turfgrass physiology and growth. These influences have been well documented (Madison, 1971; Beard, 1972; Howard, 1985; Nelson, 1985; Turgeon, 1985; Walmsley, 1985). The development of aluminium toxicity in strongly acid soils and the associated physiological disorders are discussed by Mengel and Kirkby (1987).

Soil pH also regulates the level of microorganism activity. The interaction of soil microorganisms with chemical and physical soil processes and the influence of soil pH on this desirable activity are reviewed by Rieke (1969). For many microorganism species, activity is most efficient at soil pH values near 7.0.

The 'acid theory' and its role in suppressing weeds and earthworm activity, providing a hardier turf, and a firm surface is discussed by Walmsley (1985). The acid condition leads to a finer textured turf, but pH must be carefully maintained because decreases in pH below a certain level can lead to weak turf or even turf loss.

The physical condition of the soil is also related to pH because the soil pH value provides an indication of base saturation. The influence of the nature and availability of exchangeable cations on physical behaviour of the soil has been discussed in Section 1.3 (ii).

(e) Assessment of the Status of Exchangeable Cations in Soil

Two different approaches exist for assessing the status of exchangeable cations in soils and developing appropriate fertiliser programmes.

The base cation saturation ratio concept (BCSR), aims to achieve a balance of nutrients in the soil. Ideal ranges of ion saturation were given as 65-85% Ca, 6-12% Mg, and 2-5% K by Graham (1959). Edmeades (1984) showed, however, that the standard method for determining CEC (Section 3.1) overestimates the CEC measured at field pH. This can result in an underestimation of base cation saturation ratios by up to 50%. Therefore, care must be taken when interpreting soil test results.

The nutrient sufficiency approach used by the Ministry of Agriculture and Fisheries (MAFTech) in New Zealand aims to maintain soil nutrients above critical limits. Quick Test results are closely related to exchangeable cations and are used by MAFTech to make fertiliser recommendations. Interpretation of Quick Test results is based on the probability of obtaining a response to added fertiliser. Soils in the high category (Table 1.6) will almost certainly not respond to fertiliser application.

Edmeades (1984), concluded that the nutrient sufficiency approach to soil testing, when adequately calibrated, provides the most cost-effective fertiliser recommendations.

(iii) Soil Texture

(a) **Clay Content**

Harris (1961), stated that pitch soils are selected for two essential properties; plasticity, which is the property of being moulded and shaped without rupturing, and coherence,

TABLE 1.6 Soil Quick Test categories for a number of plant nutrients.

Plant Nutrient	Quick Test Category			
	Very Low	Low	Medium	High
K	0- 4	5-6	7- 8	> 8
Mg	-	0-3	4-10	> 10
P	0-10	11-20	21-30	> 30

(Cornforth and Sinclair, 1984)

which is the tenacity with which the moulded soil mass holds together when dry and retains its hardness. Both properties depend upon the clay and organic matter contents.

Stewart and Adams (1968), reported that as concrete needs cement so a binding soil needs clay. It was thought that a well-graded series of sand and silt-sized particles could achieve a considerable reduction in the amount of clay required to fill the remaining pore space, without a corresponding reduction in binding strength. Stewart and Adams (1968), noted that an excess of clay reported for some Australian pitch soils can cause stickiness when wet and increase the severity of cracking due to shrinkage on drying. The Australian 'sticky wicket', upon drying, develops a corrugated and irregular crust of dry soil over the moist base and, from such a surface, the ball comes off with irregular height, speed and turn (Harris, 1961). The variable bounce of the Melbourne test wicket in 1983 caused by 'saucering' or curling of the soil crust is discussed in detail by McIntyre (1983b).

Stewart and Adams (1968), calculated that, in a perfect mix of the ideal combination of a uniformly-graded series of non-clay particles, 25% by weight is probably the minimum clay content capable of providing sufficient strength to bind the surface of a pitch. In so far as most soil materials are not ideally graded and cannot be perfectly mixed, clay contents between 30% and 40% are normally required. Indeed, the clay contents on county cricket grounds in England tend to fall mainly within the 30-40% range (Dury, 1987).

The study of Stewart and Adams (1969), concluded that bounce height could be predicted for properly prepared pitches from the clay content of the pitch soil as follows:

$$\text{Bounce height (inches)} = 0.43 \times \%\ \text{clay} + 10.6 \qquad [1.4]$$

Prediction on the basis of clay content alone may, however, be upset by factors influencing the effectiveness of the clay (e.g. clay type, dispersion, soil texture). In addition, actual pace developed on a pitch will depend on the efficiency with which the groundsman develops the potential soil strength available.

Harris (1961), observed that in Australia, pitch soils contain a clay 50-75%. The high clay content soils used in Australia and the West Indies, which potentially give very fast pitches are, however, generally inappropriate in England due to less favourable climatic conditions for soil drying (Dury, 1987).

McIntyre (1983a), recommended a clay content greater than 50% and if smectite forms at least 50% of the clay minerals, then the clay content should be between 50% and 60%. A higher clay content may cause excessive cracking, or cracks which are too wide. If other clay minerals such as kaolinite predominate, a greater clay content (60-75%) would probably improve pitch hardness.

McIntyre (1984b), regarded 50% to 60% clay content as essential for the swelling clay soils of New Zealand pitches, with greater than 60% of the clay minerals being smectite. He stated that it may be necessary to increase the clay content in an endeavour to make up for the hardness bestowed on Australian soils by the high levels of magnesium and calcium ions.

Cameron-Lee (1984), determined the clay contents for a number of soils used on first class pitches in New Zealand. The pitches could be divided into three groups with regard to clay content. The first group had clay contents ranging from 31-35%. They performed favourably and had lower soil moisture contents during the course of play. The second group had clay contents between 40% and 50%, and in general, these pitches were consistently slow to easy paced and were maintained at higher soil moisture contents. The third group consisted of those pitches with clay contents greater than 50%. These pitches were classed as slow to easy paced with high moisture levels during play. Cameron-Lee concluded that clay content of the pitch soil is not the only determinant of playability. Clay type, organic matter content, plant growth, soil moisture level and management practices interact to determine pitch playability.

(b) **Other Particles**

Harris (1961), noted that although a soil with high clay content may be used for pitch preparation, fractions other than the clay content endow particular attributes. English pitch making practices have shown preference for higher sand fractions, but with high organic matter contents to give the extra binding power; in South Africa the preference is for low sand and organic matter contents; while under Australian conditions, differences between soils may be illustrated by a comparison of the soil used for pitch preparation at the Adelaide Oval (30% sand, 2-3% organic matter) with that used at the Brisbane Cricket Ground (13% sand, 5% organic matter).

A cricket pitch soil with an appreciable sand fraction, particularly if coarse sand is predominant, will produce an abrasive playing surface upon which the 'shine' of the new ball will soon be lost, and a 'turning' pitch for the slow bowler may develop early in the match (Harris, 1961). McIntyre (1983a), stated that coarse sand should probably be less than 10%, although the maximum tolerable is not known. Cameron-Lee (1984), showed that most of the New Zealand first class pitch soils studied had a sand content between 10% and 20%. One venue had a sand content in excess of 30% but it was apparent from observation that most of the sand was of the fine type.

McIntyre (1983a), discussed the importance of silt particles. An excess of silt particles will reduce soil cohesion, and powdering will occur, although the critical amount depends on the amount and type of clay.

He also noted that a certain amount of organic matter in the humic (colloidal) form increases plasticity, as well as improving structural stability and hydraulic conductivity. In excess it may be deleterious and an organic matter content ≤ 5% is recommended. In contrast, Harris (1978), reported a value of 10% in the Adelaide pitch soil without apparent concern for its effect.

Cameron-Lee (1984), determined organic matter levels of a selection of New Zealand pitch soils. Values recorded (5-15%) were high relative to many overseas pitches but no correlation could be drawn between organic matter content and pitch playability. He postulated that the high organic matter levels could be explained by the slow rate of decomposition by biological processes. Compaction and water-logging (conditions commonly created on cricket pitches) limit the amount of oxygen within the soil. Further, turf management practices such as pesticide and acidic fertiliser application contribute to creating an unfavourable environment for biological activity, and organic matter accumulates.

(iv) Soil Compaction and Density

Compaction is the process of increasing soil density by packing the particles closer together. There is a reduction in the volume of air, but no significant change in the volume of water in the soil. The degree of compaction is measured in terms of bulk density[1] i.e. the mass of solids per unit volume of soil (Craig, 1983). The process of compaction must not be confused with that of consolidation (Section 1.3 (vi)).

Compaction has two important effects on soil properties:

(a) the shear strength of soil is increased due to the greater value of soil cohesion (Capper, 1976).

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[1] The term bulk density used by soil scientists is equivalent to the term dry density used by soil engineers.

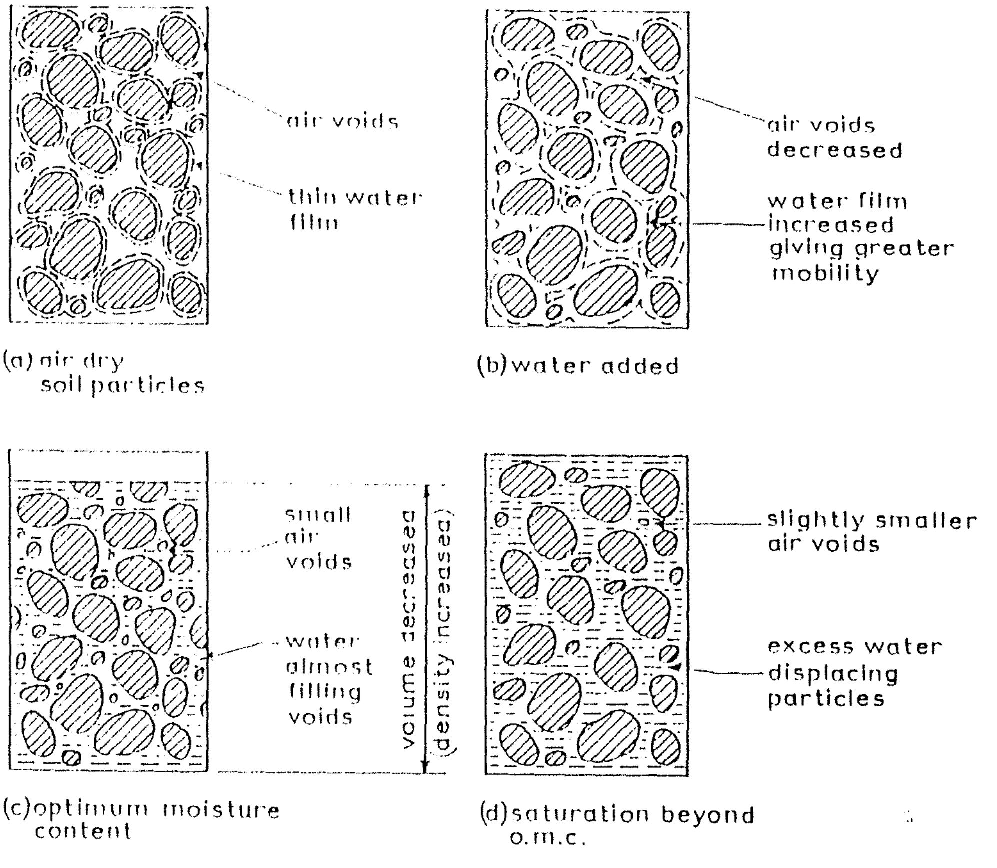


Figure 1.6 Schematic representation of the soil compaction process (Head, 1980).

(b) A high degree of compaction reduces the tendency for settlement of soil under steady and repeated loading. If large air voids are left in the soil, they may subsequently be filled with water, resulting in a reduction in shear strength. This increase in the water content may also be accompanied by swelling and loss of soil strength in soils containing smectitic clay minerals (Scott, 1980).

Compaction in a cohesive soil is accomplished by distortion and reorientation of soil particles. This process is resisted by interparticle attractive forces of cohesion. As the water content of the soil is increased soil cohesion is decreased and the resistance to compaction is reduced. Correspondingly, the compactive effort becomes more effective (Sowers, 1970). If the water content is increased beyond the point where the particles are packed together as closely as possible (bulk density is at a maximum), the excess water begins to push the particles apart and little or no air is displaced. Consequently bulk density decreases (Figure 1.6).

The bulk density of a soil after compaction depends not only on the water content at time of compaction but also on the compactive effort applied (Craig, 1983). The greater the compactive effort, (e.g. heavier the roller) the higher the maximum bulk density attainable, and the lower the optimum moisture content at which this maximum density can be achieved (Sowers, 1970).

The relationship between bulk density and moisture content is determined by the Proctor compaction test. From the compaction curve produced, two quantities can be determined:

(a) The maximum bulk density.

(b) The optimum water content at which maximum bulk density is achieved (Figure 1.7).

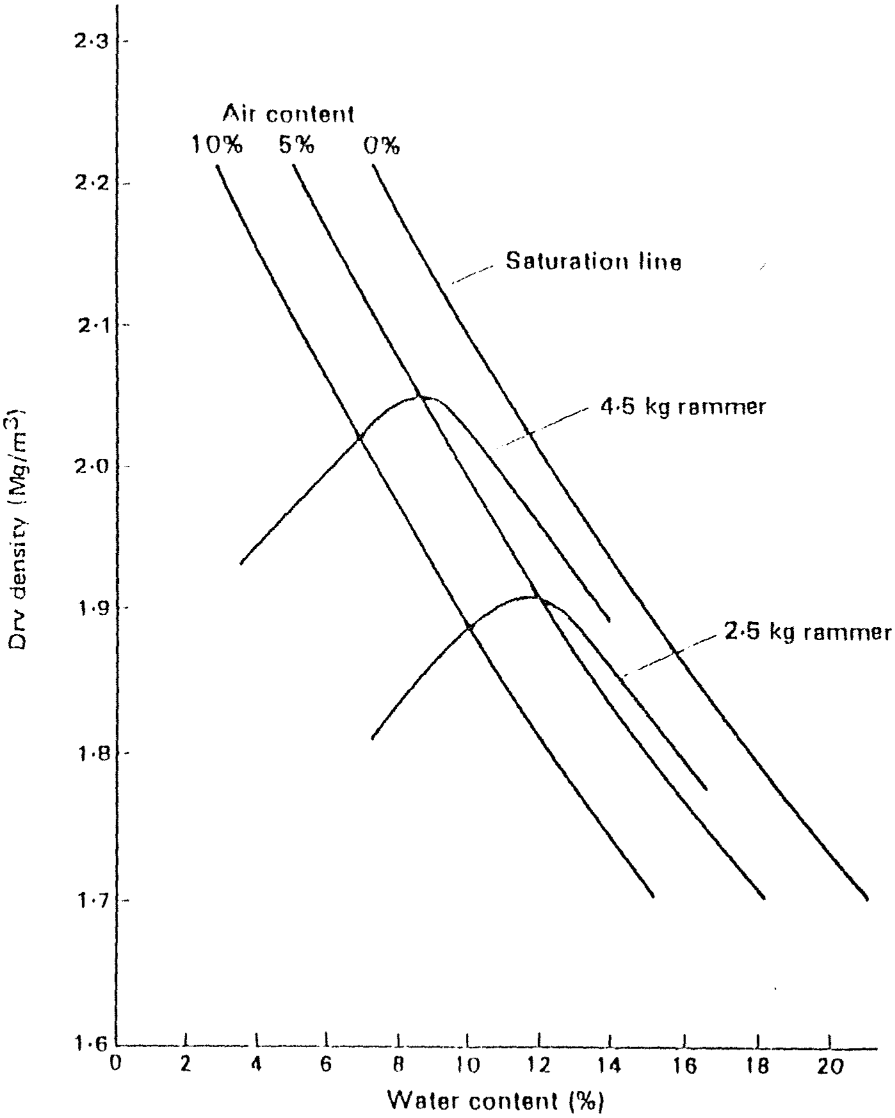


Figure 1.7 Bulk density - water content curves for different compactive efforts (Craig, 1983).

A compaction curve is not complete without addition of air void lines. These lines show the density-moisture content relationship for soil containing a constant percentage of air voids (Figure 1.7). They enable the air content at any point on the compaction curve to be determined (Craig, 1983). Generally, the lines for complete saturation, and for 5% and 10% air void ratios are shown. Maximum bulk density occurs at about 5% air void ratio or about 85-90% saturation (Scott, 1980).

Murphy (1984), postulated that if a series of compaction curves for pitch soil and rolling equipment were known at each ground, it would be possible to quantitatively determine the amount of water to be added or removed from the soil before rolling to achieve the maximum density. Murphy stated that the next stage of research needed to address the air/water ratio and the amount, timing and duration of rolling to achieve maximum soil bulk density.

Murphy (1987), investigated the influence of rolling on soil bulk density, soil moisture content, and pitch playability. He found a close relationship between soil bulk density and soil moisture content. The maximum bulk density that can be attained in a soil is determined by soil moisture content and, alternatively, the maximum moisture content that can be attained in a soil is determined by soil bulk density. Murphy hypothesised that the higher the percentage of pitch bulk density to maximum bulk density at a given moisture content (0-100 mm pitch profile) at the commencement of play, the longer the duration time before the pitch will respond to ball spin i.e. the higher the bulk density, the better the pitch will last. Thus, a 5-day test pitch will require a higher soil bulk density than a 3-day match pitch. He also stated the higher the bulk density at the start of preparation, the less water present in the soil, and consequently the less water to be lost by evapotranspiration before match commencement.

(v) Grass and the Cricket Pitch

The turfgrass plant has an important role to play in the production of a pitch having desirable performance characteristics. Harris (1961), stated that because pitch soils characteristically crack into blocks, an important function of the turfgrass plant is to provide an abundant root system which adequately anchors the blocks together, as well as providing fibrous reinforcement within the blocks. McIntyre (1983a) also stressed the importance of binding and stabilising by root and stolon ramifaction in self-mulching (crumbly) soils, such as at the Brisbane Cricket Ground. Lush *et al.,* (1985), recognised that curators ensure the grass is kept alive during preparation. Green leaves of living grass transpire water which is drawn by roots from soil below the surface. Living and dead leaves, together with any grass clippings spread on the pitch, reduce evaporation directly by shading the surface and restricting air movement. Extraction of water by grass roots below the surface, combined with reduced surface loss by evaporation, should bring about deeper and more uniform drying of the soil profile (McIntyre, 1983a; Lush *et al.,* 1985). Therefore, without an adequate grass cover, the drying pitch will not hold together and will wear prematurely. In addition, McIntyre (1983a) found that without grass, drying of the Melbourne Cricket Ground (MCG) pitch was shallow, irrespective of the amount of rolling. Curling (saucering) of the soil crust occurred, giving rise to uneven bounce. Lush *et al.,* (1985), also reported on the relationship between greenness of a pitch area and drying, as represented by cracking at the MCG. Nevertheless, pitches can be too green and in excessively leafy pitches the soil can become so dry, and the cracks so wide, that balls could bounce at odd angles. McIntyre (1983b) concluded, therefore, that removal of water evenly over a depth of 100 mm is a more important function of the grass plant than its binding role, especially when a soil has little structure.

Grasses for pitches should produce an extensive, deep root system, have a reasonable tolerance to drought and salt conditions, a good tolerance to compaction, an excellent recuperative potential and where possible horizontal growth habit (Semos, 1983). They should be selected from those species or cultivars performing well on pitches in the local region.

The type of grass favoured for pitches in Australia and other countries with warm climates is couch (*Cynodon dactylon* (L.) Pers.), a rhizomatous, warm season species. The preference for couch is probably based on its hardiness. In addition, warm season (C4) grasses are more photosynthetically efficient than cool season (C3) grasses (Turgeon, 1985). Couch will withstand close mowing to 2 mm, heavy rolling, and considerable salt, heat and water stress, and will provide considerable cover, if initially a good stand is achieved (McIntyre, 1983b; 1984b). Both the growth habit and retention of leaves with close mowing give rise to a higher leaf area index (LAI) after cutting and, thus, to more efficient transpiration (McIntyre, 1984a). The work of Lush *et al.*, (1985) at the MCG showed the leaf area per unit ground area was about 1 cm^2/cm^2 before preparation of a good pitch began, and 0.3-0.4 cm^2/cm^2 at the start of play reducing to 0.05 cm^2/cm^2 at the end of the match.

Unfortunately, while couch is widely used in Australia, much of the New Zealand climate is not suited to its growth. Any grass selected for pitches must grow well during the cricket season (summer) and for a substantial part of the year i.e. for more than seven months and not less than five months (Lush *et al.*, 1985).

Lush *et al.*, (1985), concluded that couch would grow only marginally in Auckland and Melbourne but soil heaters installed below pitch surfaces could lengthen the growing season for couch in these marginal areas. The effectiveness of this practice has not been made clear. McIntyre (1984a), called for an investigation of the feasibility of making more use of couch grass in the North Island of New Zealand. He noted that small areas of common couch were present on the Eden Park pitches in Auckland, and also found a fine-leaf couch on minor grade pitches in Nelson, in the South Island of New Zealand (McIntyre, 1984b). Beveridge (1971), stated that one of the coarser types of *Cynodon* had been introduced into Eden Park by placing runners in core holes after the initial sowing with other grasses.

Temperate species such as ryegrass (*Lolium perenne L.*), are preferred in some parts of Australia because the growing seasons for cool season grasses are considerably longer than for tropical grasses. Traditionally, in New Zealand the practice has been to use browntop bentgrass and chewings type fine-leaved fescues (Beveridge, 1971; Haycock, 1983). Haycock (1983), addressed the problems associated with such mixtures and found that establishment of browntop and fescue during the spring can be too slow for the pitch to be ready for early-season play. Moreover, browntop has a tendency to build up a thatch layer which can be a key factor in preventing a fast-paced pitch from being obtained. In addition, turf containing soft winter grasses has a greater tendency to bruise and may provide a most venomous 'greentop' pitch. Softer grasses with less hardy growth may suffer greater damage during the course of play, and have a poorer recuperative potential.

The suitability of turf-type cultivars of ryegrass for marginal climatic areas was noted by Lush *et al.,* (1985). The recent availability of cultivars including Arno, Barry, Pennfine and Sprinter, (of which Barry is the most dwarf) in New Zealand has accelerated the trend towards turf-type ryegrass use on cricket pitches. The turf type ryegrasses are finer-leaved, harder wearing, denser, and lower growing than their pasture-type counterparts.

It is difficult to maintain grass on grounds used heavily year round. For example, the effect of football at the MCG during winter is to 'wear' couch almost completely off the pitch surface. Ryegrass has been shown to recover slightly between matches, and is sown to provide a winter cover. In spring, couch starts to regenerate from rhizomes, but recovery is limited by competition from ryegrass, and couch may not be a major component of Melbourne pitches until mid-summer. It follows, therefore, that winter sports and cricket are incompatible on grounds in climates marginal for couch, unless ryegrass pitches are acceptable for much of the cricket season.

(iv) Loss of Water from the Cricket Pitch

(a) **Drying by grass (Section 1.3 (v))**

(b) **Consolidation**

Consolidation is the gradual expulsion, by continuous pressure, of water from the pores of a saturated soil (Capper, 1976). Rolling can move water upwards in a saturated soil but this water can move out of pores only if it has somewhere to go. In saturated profiles without sub-surface drainage, the only escape route is upwards, but in shallow pitches with subsurface drainage, it is possible that water moves both up and down. Lush *et al.* (1985), have recorded decreases in surface hardness suggesting water movement upwards, and increases in water potential at the base of the clay layer, suggesting movement downwards. In a clay soil the rate of water movement will depend on the soil pore size distribution (McIntyre, 1983b). McIntyre (1984b) stated, however, that consolidation by rolling can in no way substitute for drying by grasses, except at the wettest soil conditions. Figures published for clay soils indicate that even continuous consolidation for 24 hours or longer only removes a fraction of the water which must be lost (McIntyre, 1983b). Final hardening of pitches occurs by even drying to depth through water removal by transpiration of grass plants (Lush *et al.*, 1985).

(c) **Evaporation from a Bare Soil**

McIntyre (1983b), stated that while the soil surface is wet, actual evaporation will be equal to potential evaporation. The maximum daily evaporation rate will be greater than the rate at which water can move upward through the clay soil and a steep moisture gradient is formed near the surface. When the top few millimetres become air dry, water loss is reduced to a fraction of the potential. This may result in the dryer surface layers shrinking more than the wetter layers underneath. The horizontal stresses developed in a shrinking clay soil produce cracks causing horizontal failure planes at the depth of cracking. The crusts so formed between cracks ultimately curve upwards (saucering), because the stresses vary steeply with depth. Inhomogenity ensures curling is random and results in differences in elevation of the adjacent edges of some crusts. Balls striking unsupported parts of the crust lose momentum while others bounce variably, as experienced on the old MCG pitches (Lush *et al.,* 1985).

(d) **Sweating and Under Soil Heating**

When the atmosphere close to the soil surface cools during the night, an upward temperature gradient exists for some hours. This moves water upwards through the soil in the vapour form (thermo-osmosis), and it condenses on flat covers (sweating), as well as on the soil surface. The greater the amplitude of the diurnal temperature change, the greater is this effect.

Heating cables placed in the soil, (e.g. MCG - depth 150 mm) will dry the soil mainly by thermo-osmois. Semos (1983), considered that the use of heating cables is generally only justified in climates where warm season turfgrasses go dormant and are slow to recover after winter ground use. The temperatures maintained through the winter should not necessarily make the couch green but reduce the severity of dormancy. Temperatures around 10-15°C should be suitable. In pitches on which ryegrass is used, the soil temperatures should not be so high as to make the turfgrass plant succulent, or disease and wear problems will develop. McIntyre (1984b), noted that heating cables at the Manuka Oval, Canberra, are at a depth of 280 mm and seem to be more successful than at the MCG. This effect may be due, however, to other variables such as management, rather than cable depth. For example, in Canberra the heating is constant; in Melbourne it is sometimes increased temporarily in winter to dry the pitch for football.

(vii) Pitch Profile Construction

The pitch profile should be designed to:

1. Allow rapid removal of excess water and dissolved salts from the root zone area down through the profile. Excess water moves through the macropores and because aeration occurs primarily by diffusion through these large pores, excess water should be removed as quickly as possible to enhance turfgrass root growth.

2. After drainage, hold sufficient plant-available water to encourage healthy grass growth during pitch preparation and promote the development of regular cracking patterns.

(Semos, 1983; McIntyre, 1984b).

Semos (1983), stated that these conditions are met satisfactorily, and most economically by a three layer profile over a consolidated base. The construction method is designed to incorporate:

- Clay soil layer
- Intermediate layer
- Drainage layer

(a) **Clay Soil Layer**

McIntyre (1984b), addressed the problem of depth of the clay soil layer. He noted that there are two schools of thought in Australia. One group, accustomed to salt in soil or irrigation water and a clay soil with medium to low shrinkage, advocate a minimum depth of 100 mm to facilitate improved leaching capacity. The second group, accustomed to soils exhibiting a higher degree of shrinkage on drying, advocate a minimum depth of 150 mm and a preferred depth of 200 mm (Semos, 1983). This will:

- hold sufficient water for most plant requirements;

- enable the bottom half of the layer to be unaffected by rolling, thus remaining aggregated for improved water movement and aeration;
- allow some root encouragement into the underlying intermediate layer;
- prevent roller influence which can cause movement of soil at the clay soil intermediate layer interface, and movement of blocks between cracks during play.

(McIntyre, 1983a;1984b ; Semos, 1983)

McIntyre believed that shallow layers of clay soil are more prone to structural damage at the interface when rolled and, as a result, are more likely to become poorly drained.

(b) **Intermediate Layer**

Semos (1983), stated that this layer is designed to hold water and nutrients, encourage roots from the overlying clay soil and give the pitch its uniformity by producing a false water table at the intermediate-drainage layer interface. He recommended a minimum depth of 100 mm for an intermediate layer conforming to the particle size distribution presented in Table 1.7.

The use of an intermediate layer conforming to these requirements will prevent loss of dispersed clay into the drainage layer by leaching. As it overlies a coarse material (drainage layer), it retains extra water at its base but will still be well aerated and allow drainage of the clay soil layer (McIntyre, 1983a). McIntyre (1984b), used the capillary theory to explain that movement of water is better across a clay soil fine sand interface than across a clay soil/coarse-grained material interface.

Where a shallower layer of clay is used, it may be necessary to underlay it with a soil rather than sand in order to provide more plant available water. Where the soil is well-aggregated, it can be laid directly on the drainage layer. McIntyre believed that the use of any soil containing an appreciable amount of clay poses a risk in that soil structure can deteriorate through compaction and subsequently reduce water and air movement (McIntyre, 1984b).

(c) Drainage Layer

It is advisable for pitches at all levels of cricket to have free drainage below the pitch soil; for first class cricket it is essential (McIntyre, 1984b). The drainage layer is designed to be used as a water removal system which keys into drainage pipes (Semos, 1983). The construction of a drainage layer will be dependent on the type of subsoil, the presence of a water-table and the existent of field drains. The combinations are outlined below:

1. Low permeability subsoil, field drains present.

   This is the general case for first class cricket grounds. A drainage layer of coarse sand/fine gravel should be installed on a compacted base which slopes to a sump. The rate at which water reaches this drainage layer is controlled by the clay soil layer and is low, due to the low permeability of compacted clay soils. Installation of tile drains is, therefore, often not required.

2. Low permeability subsoil, no shallow water-table, no field drains.

   Drainage of the pitch soil may be achieved by creating a 'sink' below the pitch, provided water in the sink can percolate away slowly through the natural subsoil. Four layers - fine sand over coarse sand, over gravel, over broken stone - could constitute such a sink. The depth of broken stone can be determined once the rate of percolation and amount of water which needs to be held in the sink are identified.

3. Any subsoil, shallow water-table present.

   A drainage layer should be installed and the layer should contain tile drains which discharge to a sump from which water is removed (this may require a pump facility). If drainage is not feasible, a swelling clay soil should not be used for the pitch.

TABLE 1.7 Particle size distribution for the intermediate layer of a pitch profile.

Particle Size (mm)	% of Particles
2.00 - 1.00	0 or not exceeding 10%
1.00 - 0.10	75 - 95% (majority in the 0.25 - 0.50 mm range)
< 0.10	5 - 15% (clay 2-4%)

(Semos, 1983)

TABLE 1.8 Particle size distribution for the drainage layer of a pitch profile.

Particle size (mm)	% of Particles
> 8.00	0
8.0 - 4.0	0 or not exceeding 2%
4.0 - 2.8	0 or not exceeding 20%
2.8 - 2.0	0 or not exceeding 20%
2.0 - 0.5	Not less than 55%
0.5 - 0.1	0 or not exceeding 10%
< 0.1	0

(Semos, 1983)

4. Permeable (sandy) subsoil, no shallow water-table.

McIntyre (1983a), stated that if the local soil is a deep sand, the clay soil can be laid directly on it. Care must be taken not to cause compaction at the clay soil - sand interface.

(McIntyre, 1984b).

The drainage layer sand should be within the particle size distribution shown in Table 1.8. This drainage sand is designed to minimise compaction. To avoid shrinkage at a later date, it will need to be settled by watering and then rolling with a 1000 kg roller during construction (Semos, 1983).

CHAPTER 2: CLAY MINERALOGY

2.1 Methods for Clay Mineralogy Determination

(i) X-ray Diffraction (XRD)

Approximately 5 g of each soil studied were placed in 100 ml centrifuge tubes, suspended in water, and the pH raised to approximately 10 by the addition of a few drops of 1:1 ammonium hydroxide. Following ultrasonic dispersion at 20 kHz for 2 minutes, the suspension was centrifuged at 1000 rpm for 8½ minutes, after which the clay fraction (< 2μm) was decanted off and used for X-ray diffraction analysis.

A sample of ammonium (NH_4^+) saturated clay suspension was mounted on a glass slide, allowed to dry at 60° C and then introduced into a Phillips PW1840 X-ray diffractometer (Co radiation). A further aliquot of suspension was saturated with potassium (K^+) ions and scanned as described above. The K^+ saturated samples were scanned again after heating stepwise at 200°C, 300°C, 400°C and 500°C for 30 minutes. A third aliquot of clay suspension was saturated with magnesium (Mg^{2+}) ions and the X-ray diffraction analysis procedure repeated. Glycerol in ethanol (5%) was added as a mist, and diffraction analysis repeated with a view to identifying smectite clay minerals. Glycerol disturbs the weak hydrogen bonding between smectitic layers, resulting in an increase from 1.2-1.4 nm to 1.6-1.8 nm for the c-spacing of the mineral structure.

(ii) Transmission Electron Microscopy (TEM)

Approximately 1 ml of each NH_4^+ saturated clay suspension was repeatedly diluted with distilled water to produce a barely opaque suspension. One drop of suspension was placed on a carbon film supported by a 3 mm copper grid and dried at 60°C for 15 minutes. This was used for transmission electron optical study. The magnification of all electron micrographs (Plates 2.1-2.6) is 32000 diameters.

2.2 Clay Mineralogy of Pitch Soils

The dominant and minor clay minerals present in the pitch soils studied are shown in Table 2.1.

The Ward and Kakanui soils have similar clay mineral assemblages, dominated by the presence of mica and smectite. The shape of the diffraction peaks for mica in the Ward soil indicate that the mica is weathering. Smectite appears as a haze of very fine particles amongst the larger but irregularly-shaped mica flakes (Plates 2.1, 2.2), and its presence is confirmed by a shift in c-spacing from 1.2-1.4 nm to 1.6-1.8 nm after glycerol treatment.

The presence of smectite in these soils has important practical implications because such minerals possess an expanding lattice (Section 1.3 (i)) and shrink and swell with changes in soil moisture content. Shrinkage on drying, as manifested by soil cracking, is an important factor influencing pitch management and playability (Section 1.3 (i)). The high clay contents of the Ward and Kakanui soils (Table 4.1) combined with the dominance of smectite in the clay mineral assemblage probably accounts for the extensive to excessive soil cracking observed with these soils in the field (Section 6.7). As such, they can be readily classified as swelling type soils. The very fine particle size and high specific surface area (Table 2.2) of the smectites also contribute to the high plasticity indices (Table 4.4) and high cation exchange capacities (Table 3.3) of these soils.

The Marton and Palmerston North soils are dominated by mica and vermiculite (Table 2.1). The vermiculite of the Marton soil requires both potassium saturation and heating to 500°C to break the strong bonds of the interlayer Al-OH polymers. While the vermiculites may shrink and swell to a small degree (Table 2.2), the structural stability characteristic of aluminium vermiculite, and the cementing role of iron oxides present (Plate 2.3), in association with the non-expansive nature of micaceous clay minerals may together explain why the Marton and Palmerston North soils crack only slightly in the field (Section 6.7) and have low free swell values (Table 4.9). Hence they can be classified as non swelling soils.

TABLE 2.1 **Types and relative amounts of minerals present in the clay fractions (< 2 μm) of the pitch soils studied.**

Pitch Soil	Clay Mineralogy	
	Dominant Mineral(s)	Minor Mineral(s)
Redhill	Halloysite	Kaolinite
St John A	Aluminium-Vermiculite	Smectite, Halloysite Iron Oxides
St John[1]	Aluminium-Vermiculite	n.d.
St John B[1]	Aluminium-Vermicultie	n.d.
Kakanui	Mica, Smectite	Halloysite
Ward	Mica, Smectite	Halloysite
Marton	Mica, Aluminium Vermiculite	Halloysite Iron Oxides
Palmerston North[1]	Mica, Aluminium Vermiculite	n.d.

n.d. = not determined

[1] X-ray diffraction only

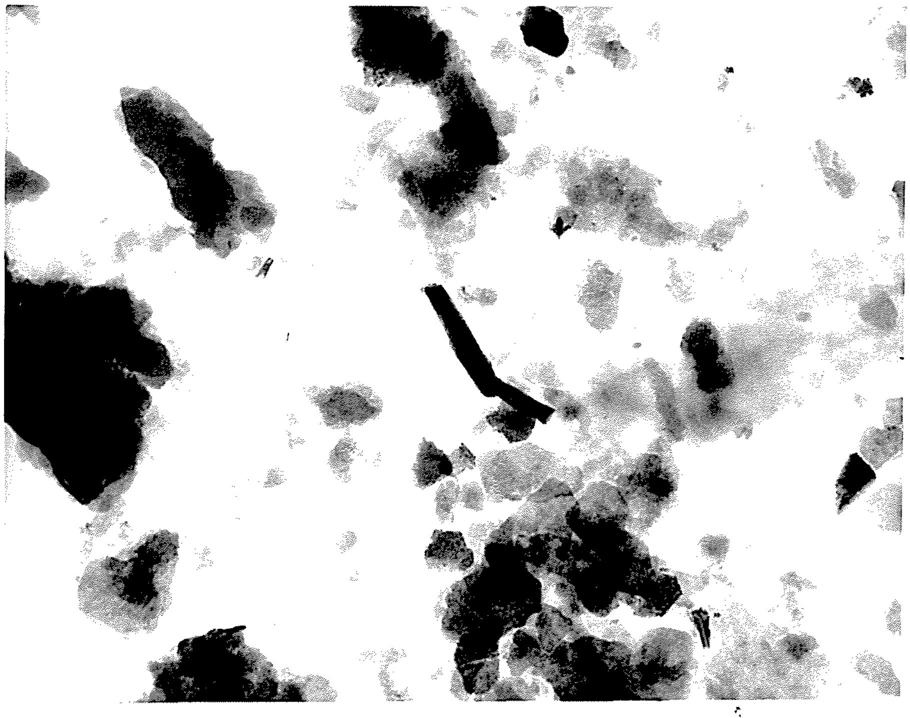


Plate 2.1 Electron micrograph showing the haze of very fine smectite particles amongst the irregularly shaped mica flakes in the clay fraction of the Ward soil.

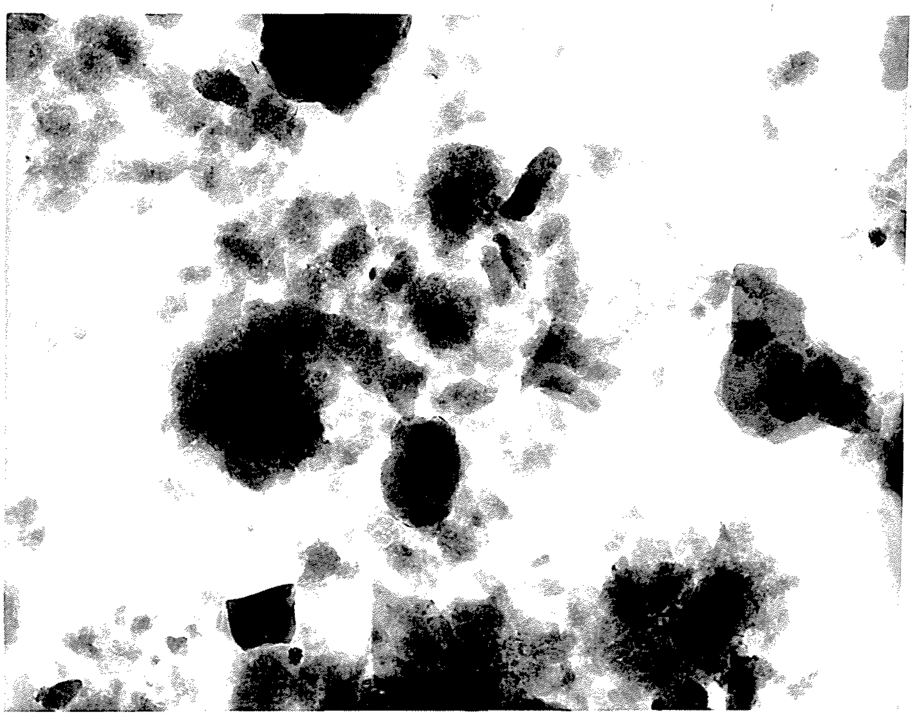


Plate 2.2 Electron micrograph showing the haze of very fine smectite particles amongst the irregularly shaped mica flakes in the clay fraction of the Kakanui soil.

Plate 2.3 shows that a small amount of halloysite is present in the Marton soil. It could be expected that the small quantity of this clay mineral would have little influence on observable soil properties.

Vermiculites characteristically have a high cation exchange capacity (Table 2.2). The CEC values recorded for both the Marton and Palmerston North soils, however, are only low to medium. It is probable that much of the permanent negative charge arising from isomorphous substitution is being blocked by non-exchangeable aluminium ions of the aluminium vermiculite material. Further, mica has only a low to moderate cation exchange capacity (Table 2.2).

Mica and vermiculite, respectively, have medium and medium to high surface area resulting in high and high to very high soil plasticity. This accounts for the high plasticity index recorded for the Marton soil (Table 4.4). Plasticity differences existing between the Marton and Palmerston North soils can most likely be explained by differences in clay content (Table 4.1) rather than by differences in clay mineral composition of these soils.

The clay fractions of the St John soils contain aluminium vermiculite and smaller amounts of smectite. While the electron micrograph (Plate 2.4) does not show the presence of smectite in the St John A soil, X-ray diffraction of the clay after glycerol addition to a magnesium saturated sample produced a peak shift typical of the expanding lattice of smectite.

The presence of smectite, even if only in small amounts, could account for the free swell values of the St John soils (Table 4.9) being intermediate between those of the non swelling Palmerston and Marton soils and the swelling Ward and Kakanui soils. The limited expansive properties of the St John soils may also reflect the stability conferred by the aluminium vermiculite and the presence of minor amounts of halloysite. In addition, iron oxides seen as small black dots coating larger clay minerals (Plate 2.4) may act as as cementing agent, binding textural particles into structural units to produce improved stability in the field.

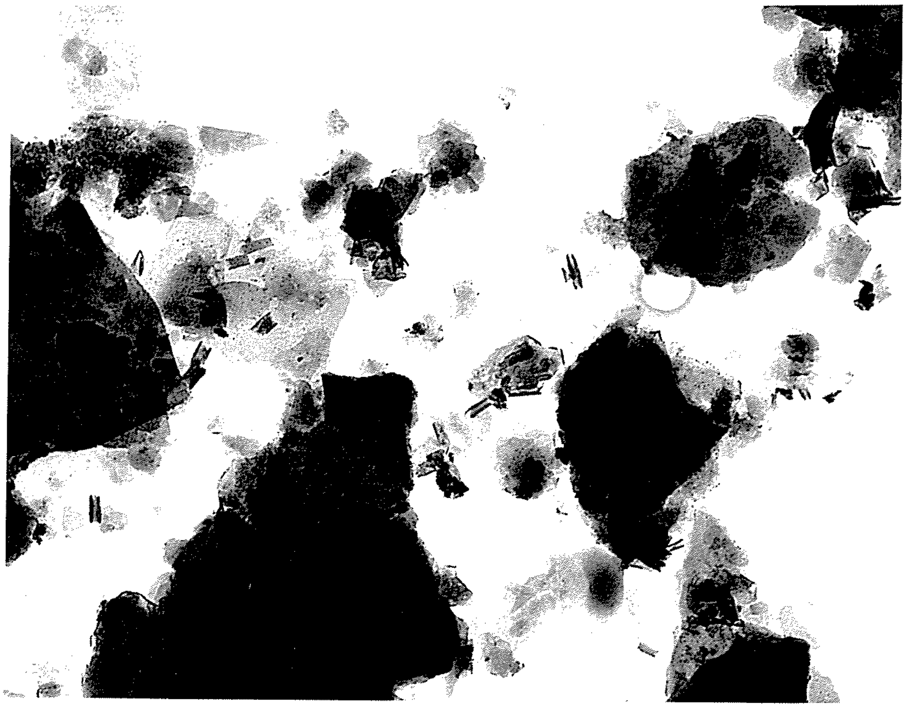


Plate 2.3 Electron micrograph showing the minor contribution of halloysite to the clay mineral assemblage of the Marton soil which is dominated by Mica and vermiculite.

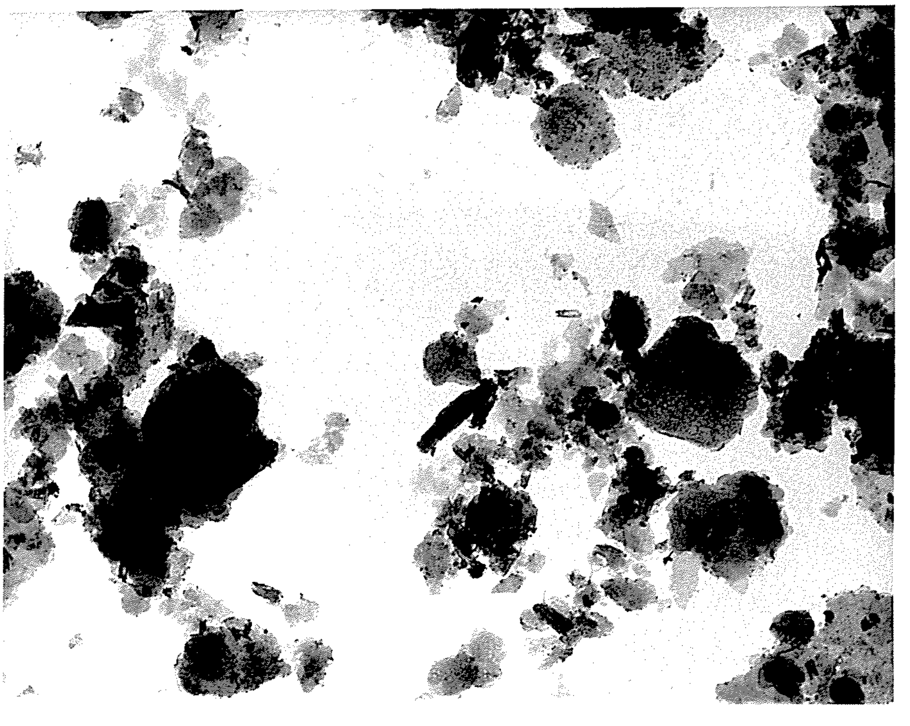


Plate 2.4 Electron micrograph of the clay fraction of the St John A soil showing the dominance of vermiculite and the presence of minor amounts of halloysite together with iron oxides, represented as small black dots coating larger clay minerals. Smectite is not readily distinguishable in the micrograph.

A moderate but acceptable level of soil cracking on drying was observed in the field for the St John soil (Section 6.7). The degree of cracking was less than that exhibited by the swelling type Ward and Kakanui soils and was probably due to the presence of a smaller amount of smectite in the clay mineral assemblage. In order to derive an adequate field description, which takes account of soil clay mineralogy and cracking behaviour in the field, it is proposed that such soils be called limited swelling types. By definition, limited swelling soils will exhibit some cracking on drying due to the presence of smectite clay minerals, but the minor contribution of such minerals to the clay mineralogy means that this cracking will not be extensive or excessive and will allow the production of a pitch of acceptable standard.

The higher CEC values recorded for the St John soils as compared to the Marton and Palmerston North soils (Table 3.3) may reflect the contribution of smectite to the clay fraction.

X-ray diffraction analyses of the Redhill soil indicate halloysite as the dominant clay mineral. This was supported by electron microscopy (Plate 2.5). TEM analysis, however, showed that minor amounts of other clay minerals are present in this soil (Table 2.1). Although these include kaolinite (Plate 2.6) and a needle-like mineral (Palygorskite ?), a more complete identification was not possible from the available information. The presence of iron oxides was also expected due to the intensely red soil colour (Munsell Value 2.5 YR 3/3), but X-ray diffraction did not indicate the presence of crystalline iron oxides. It is presumed, therefore, that the iron oxides possess only short-range order. The quantitative contribution of these minerals to the clay mineral assemblage is minor, and many of the properties shown by the Redhill soil can be explained by the presence of halloysite as the dominant clay mineral.

Halloysite has a low cation exchange capacity and high plasticity, properties characteristic of the Redhill soil. In addition, the Redhill soil is only slightly sticky when wet, a property also consistent with halloysitic clays.

Plate 2.5 Electron micrograph of the clay fraction of the Redhill soil showing halloysite as the dominant clay mineral present.

Plate 2.6 Electron micrograph of the clay fraction of the Redhill soil showing examples of the minor amounts of other minerals present including kaolinite.

Determination of shrinkage capacity (Section 4.7) shows the Redhill soil has the potential to expand and contract slightly in the field. Since smectite minerals appear to be absent, this could possibly be due to a small amount of short-range order gel material which cannot be identified by X-ray diffraction procedures but could be present as coatings on clay particles. Further work is needed to elucidate this point.

Conclusions

1. It is possible to categorise pitch soils in terms of the composition of the clay mineral assemblage.

2. Physical and chemical properties conferred by the clay fraction are very important in determining the suitability of a pitch soil. When assessing the input of clay minerals to the suitability of the pitch soil, both the relative proportions of the minerals present and the clay content (Section 4.1) must be considered. Further, the influence of pitch management may outweigh the importance of clay mineral type in determining how successfully a pitch soil performs in the field.

3. A knowledge of clay mineralogy is of greatest value in providing information about the potential shrinking and swelling behaviour of a soil. The presence of smectite indicates the potential of a soil to crack on drying. The findings of this study show that swelling soils with appreciable smectite contents are more difficult to manage than non swelling and limited swelling types, and produce inferior playability results.

TABLE 2.2 Properties of clay minerals.

Clay Mineral	Particle Shape	Particle size (μm)	Particle surface area	Stickiness	Plasticity	Ability to to shrink and swell	CEC c mol kg^{-1}
Kaolinite	Hexagonal Crystals	1.0-2.0	Low	Slight	High	None	2-10
Halloysite	Curled flakes Tubes	0.1-0.5 0.1-1.0	Medium	Slight	High	None	2-10
Smectite	indefinite	< 0.2	High	High	Very high	Great	80-120
Micas	irregular flakes	1-2	Medium	Medium	High	Very slight	10-40
Vermiculite	irregular flakes	0.5-2	Medium-high	Medium	Very high	Low-medium	Up to 160

(Adapted from Sopher and Baird, 1978)

CHAPTER 3: SOIL CHEMICAL PROPERTIES

3.1 Methods for determination of soil chemical properties

(i) Soil pH

The pH of air dried (< 2 mm) pitch soil samples was determined using a 1:2.5 soil-water slurry and a standard glass electrode pH meter (Peech, 1965). Suspensions were left to stand overnight for 24 hours, then stirred before pH measurement was made.

Samples from the plot field trial were collected at depths of 0-50 mm and 50-100 mm and pH determined as above. Unlike the above, these samples were not air dried before analysis and treatment results were combined to give the average field pH values for each soil. No significant differences in pH value were found between field trial treatments (Section 3.2) for each soil.

(ii) Soil Organic Matter

The combustion procedure (Bremner and Tabatabai, 1971), was used to quantitatively determine the organic matter content of the pitch soil samples. The instrument used was a Leco GC-90 Gravimetric Carbon Determinator and samples were combusted at 1650°C in disposable ceramic cups.

A sample of air dried soil (< 2 mm) containing a minimum of 25 mg of organic carbon was combusted in a stream of oxygen with iron, tin and copper chips added directly to the soil samples as 'accelerators'. After removal of dust, certain sulphur and nitrogen oxides, and conversion of CO to CO_2, dry CO_2 was trapped on ascarite (NaOH absorbed asbestos). The ascarite-CO_2 trap was weighed before and after each oxidation.

The amount of carbon was determined as follows:

$$\text{Carbon (mg)} = \text{Amount of } CO_2 \text{ (mg)} \times 0.2729 \qquad [3.1]$$

From the organic carbon content, it was possible to calculate the organic matter percentage by using a conversion factor which assumes the average carbon content or organic matter to be 58% (Allison, 1965).

(iii) Cation Exchange Capacity (CEC), Exchangeable Cations, and Olsen Phosphate

Cation exchange capacity was determined by the 1M ammonium acetate (pH 7) leaching method of Blakemore *et al.* (1987).

The ammonium acetate leachate was analysed for exchangeable cations using atomic absorption spectrophotometry while the sodium chloride leachate was analysed for ammonium-nitrogen (NH_4^+ -N) using an Autoanalyser (Blakemore *et al.*, 1987).

Total exchangeable bases (TEB) were calculated as the sum of the individual exchangeable bases (i.e., Ca, Mg, K, Na) when each was expressed as cmol kg^{-1}.

Calculation of percentage base saturation (BS) was as follows:

$$\text{BS (pH 7) \%} = \frac{\text{TEB (cmol kg}^{-1}\text{)}}{\text{CEC (cmol kg}^{-1}\text{)}} \times 100 \qquad [3.2]$$

Olsen soluble phosphate was determined by the method of Blakemore *et al.* (1987).

3.2 Soil pH

The soil pH values recorded for air dried samples of the pitch soils studied range from 4.8 to 7.3 (Table 3.1).

To accommodate the pH preference of perennial ryegrass (pH 6.1-7.3) and Cynodon dactylon. L. (pH 5.5-7.5), the pH of the soils, with the exception of the Ward and Kakanui, should be increased by liming to promote optimum grass growth. In particular, the strongly acid pH

TABLE 3:1 pH of air dried pitch soils and soils used at the Fitzherbert Park trial site.

Pitch Soil	Air dried soils	Trial	Modified Plot	Soils
		0-50 mm		50-100 mm
Redhill	4.8	n.d.		n.d.
St John A	4.8	n.d.		n.d.
St John B	4.9	n.d.		n.d.
Palmerston North	5.0	5.4		5.6
Marton	5.3	n.d.		n.d.
St John	5.4	5.6		5.7
Ward	6.0	6.1		6.4
Kakanui	7.3	7.1		7.3

n.d. = not determined

TABLE 3.2 Organic matter levels in air dried samples of pitch soils.

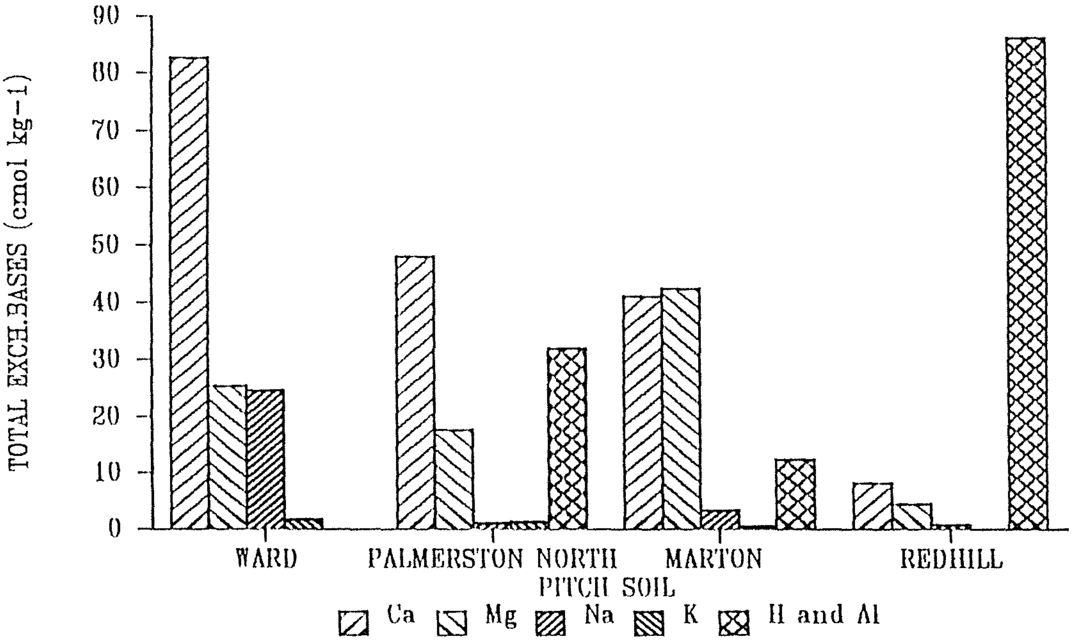
Pitch Soil	Organic Matter Content (%)
Marton	3.8
St John B	4.0
St John	4.1
St John A	4.5
Redhill	4.8
Ward	4.8
Kakanui	6.5
Palmerston North	6.7

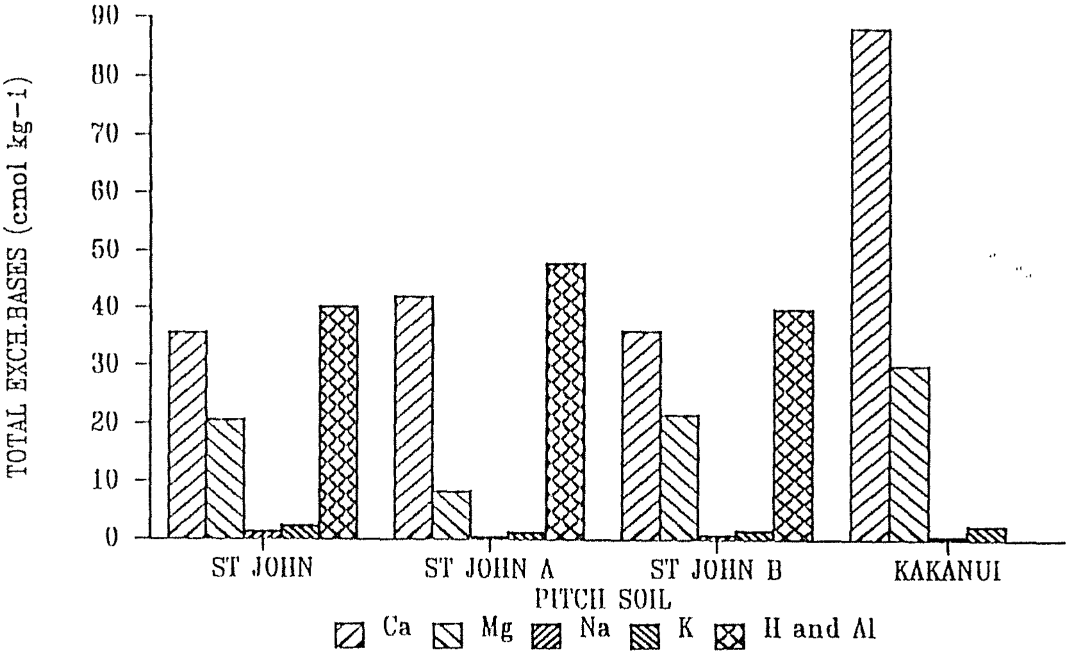
values of the Redhill, St John A and St John B soils (Table 3.1), combined with high H^+ and Al^{3+} saturation (Figure 3.1a; 3.1b), suggest a risk of aluminium toxicity. The very high levels of soluble aluminium in the Redhill soil could explain the difficulties encountered in maintaining an adequate grass cover on pitches of this soil type. Plant species and cultivars also exhibit differences in sensitivity to aluminium toxicity which could explain the improved turfgrass sward achieved with newly introduced ryegrass cultivars.

Many species of soil microorganisms prefer a soil pH near 7.0. The low pH values recorded in these soils may reduce biological activity, and also the chemical and physical benefits associated with microorganism activity (Section 1.3 (ii)). Of particular significance is the likelihood of thatch accumulation under acidic conditions. Thatch development and the corresponding reduction of pitch pace has been a major problem on lower grade pitches in Auckland (pers. com. C. Renwick). Liming to increase pH would undoubtedly stimulate microbial activity but the influence of pH on pests and diseases, soil physical condition, and nutrient availability must also be considered before recommending a liming programme.

The influence of pH on plant nutrient availability and the pH requirements of the grass species show that in most cases pH is not limiting nutrient availability and therefore grass growth. The fertility status of these soils will be discussed in Section 3.3. The Redhill soil has chemical limitations which could be overcome, in part, by increasing soil pH. An increase in the pH level of the Kakanui soil may result in development of trace element deficiencies.

It is most important to maintain a pH level which supports production of new vegetative growth following plant stress, and minimises pest and disease activity and physical damage. If no fertility limitations exist, grass establishment, growth and recovery during preparation will be maximised.





Figures 3.1a,b Comparison of levels of base saturation and exchangeable acidity in a number of pitch soils

Soil pH has an important influence on soil physical condition. Whereas nutrient availability and microorganism activity are optimised in the neutral pH range, slightly acidic soil conditions are required for non swelling soils to produce pitches without self-mulching tendencies (Section 1.3 (ii)). The acid soil pH values recorded for the non swelling and limited swelling soils studied (Table 3.1) may impart improved soil hardness. The hardness and cracking pattern of the Kakanui soil, which has a high pH due to high levels of Ca^{2+} and Mg^{2+} (Figure 3.1b), could possibly be improved by lowering the pH. It must be conceded, however, that the influence of pH on soil hardness presents an area for further study.

The modified pH values of soils used in the field trial are shown in Table 3.1. The differences recorded for air dry samples and samples taken from the trial plots may be explained by lime application to the plots during the field trial. The values given in Table 3.1 indicate that all soils had suitable conditions for plant growth. This was supported by visual observation of root development to 100 mm. The slightly lower pH values recorded in the surface 50 mm may be explained by the acidifying effect of ammonium sulphate, which was used as the nitrogen carrier during the trial.

Conclusions

1. Optimum pitch soil pH is a compromise which meets the requirements of physical and biological processes, each of which contributes to the complexity of the soil.

2. Non swelling pitch soils should be maintained at a minimum pH of 5.5, while swelling type soils can be managed at higher pH values.

3. Regular assessment of soil pH is essential to adjust the fertilisation programme to meet the needs of a dynamic system.

3.3 Soil Organic Matter

Organic matter content of the pitch soil samples ranged from 3.8% to 6.7% (Table 3.2).

It has been proposed (McIntyre, 1983a), that an organic matter content ≤ 5% is desirable. From Table 3.2 it can be seen that most of the soils studied meet this requirement.

With regard to the cricket pitch, the influence of soil organic matter can be viewed in two ways. Firstly, the higher organic matter content of the Palmerston North soil (Table 3.2) may improve its binding strength. Microbially-produced polysaccharides and clay-humic acid associations help cement soil particles into aggregates. The role of soil organic matter in developing soil aggregation, however, could be deleterious to cracking clay soils. For example, the self-mulching tendency of the Kakanui soil may be increased by further soil aggregation. The resulting strongly nutty or small blocky peds may be harder to breakdown by rolling, thereby causing the Kakanui soil to crumble into a 'mulched surface'.

The contribution of organic matter to cation exchange capacity is outlined in Section 1.3 (ii). The CEC values recorded for these soils (Table 3.3) are influenced by the organic matter contents. This contribution is possibly more important for non swelling and limited swelling types, including the St John, Palmerston North and Marton soils, as the clay mineral assemblages of these soils have lower CEC values (Table 2.2).

The improved nutrient storage and release capacity conferred by higher organic matter levels must be balanced against the negative effects of water repellency and thatch development. High organic matter levels can, however, occur without thatch development resulting if an active soil microorganism population is present in the pitch soil. Soils with high organic matter contents may also take longer to dry out due to the high water holding capacity of organic matter. Any factor which exacerbates the rate of drying of swelling type soils must be considered detrimental.In addition, waterlogged soils take longer to warm up in the spring which may slow grass establishment and growth following renovation.

Conclusions

1. Organic matter content modifies a number of important soil properties but it was not possible from this study to draw direct correlations with pitch performance.

2. The influence of soil organic matter content must be considered as a single input in an integrative soil selection and management system.

3.4 Soil Fertility

An assessment of soil fertility for the pitch soils studied is given in Table 3.3 using MAFTech guidelines (Section 1.3 (ii)).

With the exception of the Kakanui soil, results from Table 3.3 show that available phosphate levels are low to very low in each of the pitch soils studied. While turfgrass plants require only small amounts of phosphate, the results suggest that a plant growth response could be obtained by phosphate addition to these soils. In particular, the values recorded for the St John, St John A, St John B soils and Redhill soils (Table 3.3) indicate a phosphate deficiency which probably limits turfgrass growth. Care must be taken, however, not to apply fertiliser to the surface because a high phosphate concentration near the surface can promote shallow rooting. As a result, the desirable functions of the grass plant may not be fulfilled. It is desirable, therefore, that phosphate application be made at the time of pitch construction and incorporated into the soil at depth or, alternatively, soluble phosphate may be applied to existing pitches. Development of specific phosphate fertiliser programmes would require the phosphate retention characteristics of the soils to be evaluated. These were not determined in this study.

Quick Test values for magnesium are very high for all soils studied. The practical implication of these high levels is that any liming material used to increase soil pH need not include magnesium.

TABLE 3.3 Soil pH, Olsen Phosphate, MAFTech Quick Test values, and soil test categories together with the potential fertiliser response for the pitch soils.

					MAFTech Quick Test Values, Soil Test Categories and Potential Fertiliser Response						
Pitch Soil	pH	Olsen P	Category	Response	Ca[1]	Mg[1]	Category	Response	K	Category	Response
St John	5.4	1	Very low	High	11	93	High	Low	8.4	High	Low
St John B	4.9	1	Very low	High	11	96	High	Low	5.7	Low	High
St John A	4.8	6	Very low	High	10	29	High	Low	3.3	Very Low	High
Kakanui	7.3	38	High	High	43[2]	216	High	Low	14.8	High	Low
Ward	6.0	16	Low	High	39[2]	179	High	Low	10.5	High	Low
Palmerston North	5.0	17	Low	High	11	59	High	Low	3.5	Very low	High
Marton	5.3	17	Low	High	10	159	High	Low	1.8	Very low	High
Redhill	4.9	9	Very low	High	3	22	High	Low	0.0	Very low	High

[1] Converted from exchangeable cations (cmol kg^{-1}) to Quick Test values using published conversion factors (Cornforth and Sinclair, 1982)

[2] Overestimated due to the presence of free calcium in the soil solution.

As expected, the levels of exchangeable calcium are related to soil pH. The soils with pH values less than 5.5 have low Quick Test values (Table 3.3) and low levels of calcium saturation (Figures 3.1 a; 3.1 b). The use of liming materials to increase calcium levels and soil pH in order to create a more favourable environment for turf growth has been discussed in Section 3.2.

Quick Test values for potassium are very low for the Palmerston North, Marton, Redhill and St John A soils and low for the St John B soil. This would suggest that these soils could produce a growth response with potassium fertiliser application. The Quick Test values are, however, at odds with interpretation by the nutrient balance approach, which finds only the Redhill soil potassium deficient and the Marton soil marginally potassium deficient (Table 3.4).

A possible explanation for the discrepancy between Quick Test values and nutrient balance estimates of exchangeable soil potassium could arise from the conversion of soil test results (cmol kg^{-1}) to Quick Test values. Quick Test results are based on the use of a volume of soil rather than a weight, and assume a soil bulk density of 0.9 Mg/m^3. As the pitch soils studied in the field trial were characterised by bulk density values approaching 1.6 Mg/m^3 (Section 6.6), this assumption is unlikely to hold true. The measured Quick Test values for exchangeable cations could therefore be up to double those given in Table 3.3 by conversion from cmol kg^{-1}. On this basis only the Marton and Redhill soils would be limited by low levels of soil potassium. This is consistent with the findings of the nutrient balance approach. For these soils an improvement in turfgrass hardiness, disease resistance, and transpiration efficiency may result from potassium fertiliser application.

In general, the soils studied have cation balances considered satisfactory for plant growth. When interpreting these results, the underestimation of base cation saturation ratios by up to 50% (Section 1.3 (ii)) has been taken into account, along with the influence of soil pH.

TABLE 3.4 Cation exchange capacities, percentage base cation saturations, total exchangeable bases and the level of exchangeable acidity for the pitch soils studied.

Pitch Soil	Cation Exchange Capacity (cmol kg^{-1})	Base Cation Saturation (%)				Total Base Saturation (%)	Exchanged Acidity[1] (H^+ and Al^{3+}) (%)
		Ca	Mg	Na	K		
St John	18.9	35.6	20.7	1.3	2.3	59.8	40.2
St John B	18.6	36.1	21.7	0.8	1.6	60.1	39.9
St John A	14.6	42.0	8.4	0.5	1.2	52.1	48.0
Kakanui	30.2	88.3	30.1	0.6	2.5	121.5[2]	0.0
Ward	29.6	82.7	25.4	0.7	1.8	110.6[2]	0.0
Palmerston North	14.1	48.0	17.6	1.1	1.3	68.0	32.0
Marton	15.7	41.1	42.5	3.4	0.6	87.6	12.4
Redhill	20.2	8.2	4.5	0.8	0.0	13.6	86.4

[1] Calculated as the difference between cation exchange capacity and total exchangeable bases

[2] Overestimated due to the presence of free calcium in solution

An exception is the Redhill soil, which has a low level of calcium, little potassium (Table 3.4), and high H^+ and Al^{3+} saturation (Figure 3.1b). The high exchangeable acidity as a percentage of cation exchange capacity lends support to the possibility of aluminium toxicity detrimentally affecting turfgrass growth in this soil. Manipulation of the Redhill soil fertility status is essential if the benefits of a healthy, actively growing turfgrass cover are to be fully realised. Given the soil water release characteristics of the Redhill soil (Table 4.2), an extensive deeply-rooted sward is essential for pitch drying to levels required for development of acceptable playability characteristics.

The exchangeable sodium percentage (ESP) is analagous to the base saturation of sodium ions (Table 3.4). The influence of sodium ions on the physical properties of pitch soils has been discussed in Section 1.3 (ii). Results in Table 3.4 show that ESP values are below the maximum value of 5 and desirable value of 3 proposed by McIntyre (1983a). Although ESP values are low, the non swelling and limited swelling pitch soils used in the field trial appeared to be sufficiently dispersed to facilitate compaction by rolling. An investigation of the influence of increasing sodium saturation on soil physical properties may provide useful information. The development of soil aggregation in swelling soils may be reduced, and improved soil compaction may be obtained if such soils have a higher but not excessive ESP value.

Conclusions

1. Interpretation of soil test results must be done with care. Recommendations made from Quick Test results must take into account the higher soil bulk density associated with cricket pitches. Assessment of fertiliser requirements by the nutrient balance approach must allow for the errors associated with measurement of cation exchange capacity at a pH value greater than the field pH values commonly recorded for non swelling and limited swelling pitch soils.

2. The limited information available for fertility requirements of turf type grasses on cricket pitch soils makes extrapolation of existing results difficult.

3. Despite these limitations, a knowledge of levels of soil exchangeable cations is important so that any chemical restrictions reducing turfgrass growth, in an otherwise suitable pitch soil, can be overcome by fertiliser application.

4. While the nutritional role of exchangeable cations is important for balanced turfgrass growth, such growth is probably limited to a greater extent by other factors such as soil compaction and plant stress during preparation.

5. Maintenance of exchangeable cations at levels allowing maximum vegetative growth may improve turfgrass response to the stresses of pitch preparation and may ultimately result in a more efficient turf cover in what is an unfavourable physical rooting medium.

6. The role of exchangeable cations in modifying such properties as soil hardness, ability to shrink and swell and soil physical condition requires comprehensive study and is certain to provide a wealth of useful information.

CHAPTER 4: SOIL ENGINEERING PROPERTIES

4.1 Methods for determination of soil engineering properties

(i) Particle size analysis

Particle size analyses of the pitch soil samples were determined using the 'pipette method' (Thomas, 1973). The procedure was modified by excluding the acidification step. The coarse and fine sand contents of the soils were determined by wet sieve procedures (Head, 1980).

(ii) Soil water retention characteristics

Pressure plate apparatus was used to determine the water retentivity (gravimetric water content) of the soil samples at specific matric potential values. A general outline of this procedure is given by Richards (1965).

Air dried (< 2 mm soil samples) at two potentials, -0.1 and -15 bar, were used to approximate stress point (SP) and permanent wilting point (PWP), respectively. The soil water content at which plant growth is significantly affected by water deficiency is the stress point. The permanent wilting point is the water content at which plants have extracted all the 'available' water from the soil.

Field capacity (FC) values were obtained by sampling the pitch trial plots approximately 24 hours after irrigation to saturation. Determination of FC gravimetric water content is described in Section 6.1. Field capacity is an estimate of the upper limit of water that can be stored in the soil profile.

Gravimetric water contents for FC, SP, PWP and optimum rolling points (ORP) were converted to volumetric water contents using measured field density values (Section 6.1). The following estimates of available soil water were then calculated:

Total available water (TAW) $= (\theta_{FC} - \theta_{PWP})_Z$ [4.1]

Readily available water (RAW) $= (\theta_{FC} - \theta_{SP})_Z$ [4.2]

Optimum Rolling Available Water (ORAW) $= (\theta_{FC} - \theta_{ORP})_Z$ [4.3]

where Z is the effective rooting depth (assumed as 100 mm).

θ_{FC} is the volumetric water content at field capacity.

θPWP is the volumetric water content at permanent wilting point.

θSP is the volumetric water content at stress point.

θORP is the volumetric water content at optimum rolling point.

(iii) Soil plasticity

Soil liquid limits were determined by the Casagrande Method using standard Casagrande apparatus and the procedure of Head (1980).

The water content of each air dried (< 425 μm) soil sample was increased above the liquid limit. Samples were equilibrated overnight in airtight containers, and progressively dried between each determination of points on the flow curve (number of blows of Casagrande apparatus *vs* Soil water content).

Soil plastic limits were determined by the method of Head (1980). The water content of each air dried soil sample (< 425 μm) was increased to a point higher than the plastic limit. Samples were equilibrated overnight in airtight containers, then slowly dried until the plastic limit was approached. 6 mm threads were formed and rolled to 3 mm diameter, the plastic limit being reached when the thread first crumbled (Head, 1980).

The plasticity index was taken as the difference between the gravimetric water content values representing the liquid and plastic limits for each soil.

(iv) Soil Compaction

For compaction studies the Proctor compaction testing procedures and apparatus were used (Head, 1980).

The standard mould used was the old 'Proctor' mould with a volume of 944 cm^3. The soil was compacted in 3 layers for the 'ordinary' Proctor test and 5 layers for the 'heavy Proctor' test by applying respectively 25 blows of the 2.5 kg and 4.5 kg rammer from controlled heights of 300 mm and 450 mm. A minimum of five compactions were made for each soil type and each compaction test. Values of soil water content were plotted against corresponding values of soil bulk density for both ordinary and heavy compaction and compaction curves were constructed. From the curves, maximum levels of density and corresponding optimum rolling water contents (ORP) were identified for each soil.

(v) Empirical Tests

Four simple empirical tests (Head, 1980), were used to characterise the pitch soil samples.

Prior to tests the moisture content of each air dried, 1 kg soil sample was adjusted to a point considered suitable for puddling.

(a) Pinch Test

- The soil was kneaded by hand and a ball formed about 75 mm in diameter. The soil must not be cracked at this stage.

- The ball was then squeezed flat by hand onto a hard surface until it formed a disc 25 mm thick.

- There should be no cracks for the soil to pass the test.

(b) Tenacity Test

- The soil was rolled by hand into a cylinder 300 mm long and 25 mm in diameter.

- The cylinder was held up vertically by hand from one end so that 200 mm was unsupported for a period of 15 seconds.

- The soil should support its own weight to pass the test. Any stretching or cracking which occur should be recorded.

(c) Elongation Test

- The soil was rolled by hand into a cylinder 30 mm long and 25 mm in diameter.

- Each end was gripped firmly in the hands, leaving 100 mm unsupported.

- The cylinder was held horizontally, and stretched gradually by pulling with both hands until it broke.

- The length of neck formed at failure and the type of break should be recorded. The longer the neck formed, the more suitable the soil.

(d) Soaking Test

- A ball of soil 50 mm in diameter, and without cracks was made.

- It was placed in a clear container and covered with water.

- The condition of the soil ball was recorded at ½, 1, 2, 4, 8, 24 hour 2, and 4 day intervals after immersion. A suitable soil should not disintegrate.

(e) Soil Shrinkage

The free swell test is described by Head (1980). 10 ml of loosely packed, oven dry (105°C) soil (< 425 μm) was 'drizzled' into a 50 ml measuring cylinder containing 50 ml of distilled water (Figure 4.1). Free swell was calculated as the change in volume of dry soil, expressed as a percentage of its original volume:

$$\text{Free swell (\%)} = \frac{V - 10}{10} \times 100\% \qquad [4.4]$$

where v is the final volume of water and added soil.

Linear shrinkage was determined using a method adapted from Head (1980). Approximately 150 g of air dried (< 425 μm) soil was mixed to a smooth homogeneous paste at about the liquid limit and then placed in a standard mould (140 mm long; 30 mm diameter). Each mould was slowly air dried for 7 days until the soil bar had shrunk away from the walls of the mould. Soil bars were then dried at 60°C for 24 hrs and the drying temperature was increased to 105°C when shrinkage had virtually ceased.

Linear shrinkage was calculated as a percentage of the original length of the specimen.

$$\text{Linear Shrinkage (LS) (\%)} = \left[1 - \frac{L_D}{L_o}\right] \times 100\% \qquad [4.5]$$

where L_o is the original length (mm)
L_D is the length of the dry specimen (mm)

Volumetric shrinkage of the whole soil involved wetting up approximately 150 g of air dried (< 2 mm) soil to a smooth homogeneous paste at about the liquid limit. The soil was then placed in a cylindrical mould approximately 50 mm long and 47 mm in diameter (measured accurately using vernier calipers). Each mould was slowly air dried until the soil had shrunk away from the walls.

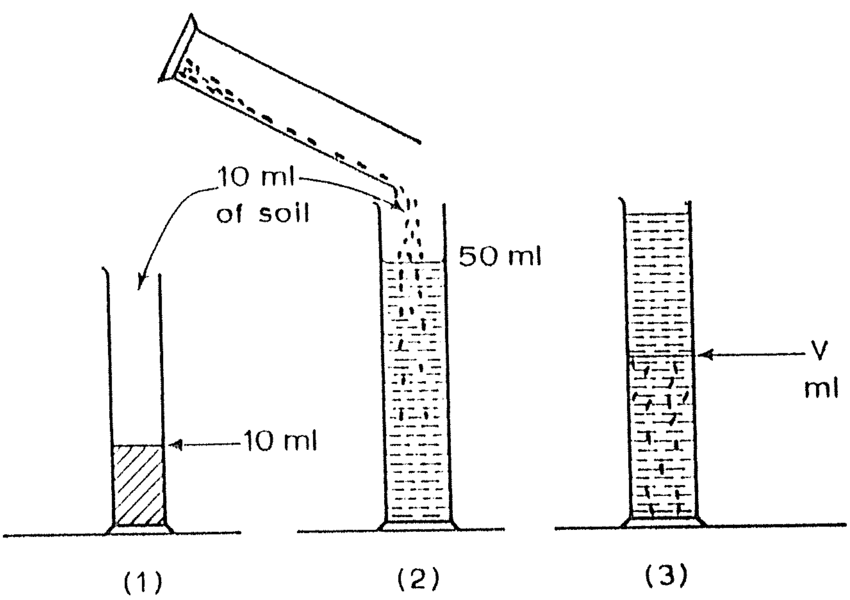


Figure 4.1 Schematic representation of the free swell test procedure (Head, 1980)

Soil cylinders were transferred to an oven for drying at 60°C and then 105°C for 24 hours.

Volumetric shrinkage was calculated as a percentage of the original volume.

$$\text{Volumetric Shrinkage (\%)} = \left[1 - \frac{V_D}{V_O}\right] \times 100\% \qquad [4.6]$$

where V_O = volume of dry soil (cm^3)

V_D = original volume of soil (cm^3)

4.2 Particle Size Analysis

The percentages of sand, silt and clay-sized particles (soil texture) determined for each pitch soil studied are shown in Table 4.1.

Results in Table 4.1 show that the silt contents of the soils are within a well-defined range of 16% to 30%, and are sufficiently low that they are unlikely to detrimentally affect soil properties such as cohesion, compaction, water movement, and aeration. In comparison, differences between sand and clay percentages are more pronounced, the percentages being in inverse proportion to each other (Table 4.1).

The sand contents of the pitch soil samples range from a low of 10% for the Ward soil to a high of 50% for the Palmerston North soil (Table 4.1). The high sand content of the Palmerston North soil, and the difference in soil texture between the Palmerston North and Palmerston North[86] samples, may be explained by the soil mixing process used. The Palmerston North soils represent a 3:1 Marton-local soil mix. Variation in the textural properties of the local soil, the selection of which is not standardised (pers. comm K. Timms), could account for the differences in sand and clay contents. In addition, error during soil mixing may have altered the soil mix ratio. So far as the present study is concerned, non-uniform mixing could mean that the soil samples collected are not representative of the bulk of the mixed soil.

Table 4.1 The percentages of sand, silt and clay-sized particles in the pitch soils studied.

Pitch Soil	Particle Size Analysis				
	% Sand			% Silt	% Clay
	Total	Fine	Coarse		
Palmerston North	50	97	3	22	28
Palmerston North[86]	38	95	5	26	36
St John A	35	90	10	29	36
St John	35	86	14	23	42
St John B	34	85	15	23	43
Kakanui	33	89	11	20	47
Marton	27	77	23	23	50
Redhill	15	77	23	16	59
Ward	10	81	19	30	60

This anomaly in soil texture highlights the difficulties associated with accurate mixing of soils for pitch use. To achieve accurate soil mixing a number of important points must be considered:

(i) Mixing must be undertaken using a specified volume or mass measure to ensure consistency and reproducibility. This is especially important where the ratio of the mix influences such properties as soil hardness (Section 5.5) and the extent of soil shrinkage and cracking (Section 4.7). Mixing must be thorough and uniform.

(ii) Mixing must always be carried out off-site. For first class pitches where financial constraints are not limiting, greater efficiency and uniformity may be achieved by utilising commercial soil blending equipment and processes.

(iii) Soil supplies must be continuous and consistent for each soil used in the mix. New supplies of a soil must be assessed for sand, silt, and clay content to eliminate the possibility of soil layering developing through topdressing of pitches with a soil of different texture.

From Table 4.1 it can be seen that a number of the pitch soils studied have high sand contents. This may have practical implications for pitch playability. Loss of ball shine by wear and increased surface roughness bestowed by sand grains may result in increased ball-surface friction and therefore ball gripping on the pitch, leading to development of spin. In addition, the presence of a high sand content in a pitch soil may reduce the potential to produce a glazed, frictionless surface by rolling (Section 1.3 (iii)) and contribute to a loss of potential pitch pace. These trends will be accelerated if the sand fraction contains a high percentage of coarse sand particles.

The percentages of fine and coarse sand for a number of the pitch soils are shown in Table 4.1. The results suggest that although the soils have high sand contents, fine sand is dominant. This, combined with the medium to high clay contents, reduces the possibility of adverse properties developing. Perhaps of greater importance is the influence of sand grain shape. Angular, sharp particles could cause greater ball wear than smooth, rounded types. This may provide an area for further investigation.

Results in Table 4.1 show that clay contents of the soils vary considerably. It could be expected that properties such as soil cohesion, plasticity, cation exchange capacity, and shrinkage would be more strongly expressed in the high clay content Ward and Redhill soils. Clay content alone, however, does not provide a direct indication of properties such as soil binding strength. The Redhill soil has a high clay content (Table 4.1) but very low A.S.S.B. Test value (Table 5.1). Similarly, the Kakanui soil, despite having a lower clay content than the Ward soil (Table 4.1), produces motties of greater strength (Table 5.1). Although the Redhill and Marton soils have high clay contents, the Redhill soil has only a low cation exchange capacity and the Marton soil has only a limited ability to shrink and swell with changes in soil water content. A relationship therefore exists between clay content and clay type. Clay content alone does not provide a reliable indication of pitch playability; only when it is combined with a knowledge of the types and amounts of individual clay minerals present in the clay fraction can soil behaviour be understood.

It could be expected that an improvement in soil hardness, wear, and ultimately pitch pace, could be achieved by increasing the clay content of a non swelling soil. The Palmerston North, Palmerston North[86] and Marton soils have similar clay mineral compositions (Table 2.1) but different clay contents (Table 4.1). As the clay content of these non swelling soils is increased from 28% to 36% to 50% respectively, soil binding strength (Table 5.1), cohesion, and plasticity (Table 4.4) increase. An alteration of the ratio of the Marton-local soil mix has been used successfully by the groundsman at Fitzherbert Park to increase pitch soil clay content and overcome the wear problems associated with this pitch soil in the past (Plate 4.1).

Plate 4.1 Soil wear on the Palmerston North soil after the Central Districts vs Northern Districts fixture (February, 1988) at Fitzherbert Park, Palmerston North.

From Table 4.1 and the results of Cameron-Lee (1984), it can be seen that soils containing a dominance of smectite clay minerals usually have high clay contents. While the properties of cohesion and plasticity associated with smectites are desirable, the high clay content-swelling mineral combination also means that other properties such as shrinkage and cracking on drying and soil water holding capacity are strongly expressed. This can make pitch management very difficult, and may often result in the production of inferior playing surfaces. Perhaps such swelling type soils could be more easily managed by reducing the clay content through modification with sand or a light textured soil. Modification of swelling soils was not attempted in this study, and therefore no recommendations can be made.

The relationship between clay content and clay type is also highlighted by the St John soil types. Despite the medium to high clay contents of these soils, the contribution of smectite to the clay mineralogy is small enough to prevent the properties of this clay mineral being strongly expressed (Section 2.1). An increase in clay content of the St John soil by addition of a high clay content non swelling soil may increase soil binding strength (Section 5.5) and eliminate crumbling at crack edges. This is a reason for modification of the St John soil by mixing with the Marton soil to improve playability.

The differences between the St John, St John B and St John A soils with regard to clay content (Table 4.1) may be important. The St John A sample represents an additional source of the St John soil, so care must be taken to prevent layering when topdressing existing St John pitches with this lower clay content soil. Given the similarity in sand percentages of these soils and the buffering capacity of the soil system, it is doubtful, however, that these differences would be significant enough to influence management and playability.

Conclusions

1. Sufficient clay must be present in the pitch soil to provide the cohesion necessary for soil binding. The degree of cohesion was acceptable for the non swelling-low clay content (< 35%) soils investigated in this study but an increase in pace and a reduction in wear may be achieved by increasing the clay content. Should any modification of a pitch soil be attempted by the mixing of different soils it would be essential to ensure uniformity of mixing, a specified ratio of materials, and accuracy and quality control.

2. Swelling soils characterised by higher clay contents (>45%) are more difficult to manage. Reduction of clay content with a corresponding dilution of properties bestowed by the clay minerals could produce more easily managed soil. This requires further investigation. A strong relationship exists between clay type and clay content. Both properties must be considered when selecting a suitable pitch soil.

3. Clay type determines many of the physical and chemical properties of the soil, while clay content determines how strongly these properties are expressed.

4. Sand content and shape of sand grains may have important practical implications for ball wear and the development of spin.

5. Relationship of clay content and clay type to the level of cricket:

   (a) low clay content (30%-40%), non swelling soils may be of particular value for lower grade cricket, where time and management inputs are limited, especially if climate is marginal.

(b) higher clay contents (> 40%) in non swelling or limited swelling soils may produce faster pitches with more acceptable wear for first class cricket.

(c) high clay contents in swelling type soils have the potential to produce hard fast pitches but are difficult to manage, and require a high level of expertise and favourable climatic conditions if a pitch of acceptable standard is to be produced.

4.3 Pitch Soil Water Retention

Gravimetric water content values for field capacity (FC), stress point (SP), permanent wilting point (PWP) and optimal rolling point (ORP) are given in Table 4.2 for each of the pitch soils studied.

When these values are related to measured water contents during preparation it becomes apparent that the sward was under water stress for a large part of the preparation programme.

Values obtained for stress point (Table 4.2) are slightly higher than water contents considered optimal for rolling (Section 4.5). This means that water stress may be affecting plant growth at the commencement of rolling.

Maintenance of an actively growing turf cover during preparation is essential if the role of the grass plant in drying the soil evenly to depth is to be realised (Section 1.3 (v)). Syringing during the hottest part of the day to slow the rate of transpiration may help alleviate turfgrass stress.

Permanent wilting point values for the Palmerston North, St John, Kakanui, and Ward soils correspond to the minimum levels of soil moisture attained in the surface layer during the field trial (Table 4.2). For these soils the grass plants extracted water from the soil to a level required for production of an acceptable pitch.

TABLE 4.2 A comparison of match day trial plot water content with average gravimetric water content values for the pitch study soils at -0.1 bar and -15 bar matric potentials, field capacity, and optimum rolling point.

Pitch Soil	FC[1]	ORP	SP	PWP	Match Day[2]	
	(%)	(%)	(%)	(%)	0-25 mm	50-75 mm
Palmerston North	29.0	21.0	22.0	14.1	14.1	17.1
Marton	n.d.	22.0	28.6	19.5	n.d.	n.d.
St John	30.0	24.0	23.2	16.4	16.7	22.5
St John A	n.d.	n.d.	23.5	14.1	n.d.	n.d.
Redhill	n.d.	34.0	35.3	29.4	n.d.	n.d.
Kakanui	33.0	23.0	24.9	16.7	17.4	25.9
Ward	41.0	29.0	31.1	21.2	21.1	25.7

n.d. = not determined

[1] Field capacity measured approximately 24 hours after irrigation

[2] Combined treatment means for the second preparation of 1986/87 and 1987/88

Generally, soil drying to at least permanent wilting point is required to develop the soil hardness for optimum bounce and pace. Although such a value of water content is reached in the surface 25 mm, drying to such a soil moisture content does not occur beyond this depth (Table 4.2). There could be a number of explanations for this phenomenon, but two possibilities warrant particular consideration. Firstly, most grass plant root activity occurs in the surface soil. Deeper root development is often restricted by physiological factors or by a soil physical condition, such as compaction. The reduced extent and, therefore, effectiveness of the root system at depth will result in lower rates of water uptake by the grass plant in this region of the soil profile. Secondly, evaporation directly from the soil surface can become a significant water loss mechanism if bare patches develop on the pitch. Evaporation causes a steep moisture gradient which can increase drying of the surface layer until the soil surface becomes approximately air dry. Therefore, it is advantageous to retard the intensity of sun and wind in order to slow down the rate of surface evaporation. Retardation of evaporation can provide a greater opportunity for prolonged evaporative water loss from the soil and provide grass plants with a greater opportunity to utilise moisture in the lower soil layers. Further, slowing down the rate of bare surface evaporation can help minimise the development of cracking. In practice this can be achieved by using shade cloth or adopting an irrigation regime (high frequency, low volume) that maintains a moist soil surface (Section 6.9).

The permanent wilting point value for the Redhill soil is considerably higher than that required in the final stages of pitch preparation (Table 4.2). This indicates a water loss mechanism other than transpiration would be necessary to facilitate pitch drying to levels which ensure suitable playability.

A study of the effect of rate and extent of turfgrass transpiration on drying of the cricket pitch is required before any conclusions can be drawn.

In Table 4.3 volumetric water content values are presented for field capacity (FC), stress point (SP), and permanent wilting point (PWP). By combining these parameters with a consideration of plant rooting depth (Z), it is possible to determine equivalent depths of water in the soil (Section 4.1). These results can then be used to determine the length of time required to achieve a defined soil moisture level in response to a given evaporative demand. By combining total available water with the rate of evaporative loss, it is possible to determine the minimum time required to reach match day soil dryness. Table 4.3 gives the time intervals following watering to saturation to reach stress point and permanent wilting point for the trial pitch soils. While both readily available water and total available water vary with soil type, the time interval to reach stress point or permanent wilting point is not markedly different between the soils studied. Table 4.3 shows that stress point is potentially achieved 2 to 4 days and permanent wilting point 5 to 7 days after watering to saturation. This assumes a uniform soil profile and uniform drying to depth, factors which may contribute to differences between hypothesised and actual time intervals. For this reason, fine-tuning should be undertaken through regular soil water content sampling during preparation.

The Ward and Kakanui soils have higher levels of readily available and total available water than the Palmerston North and St John soils (Table 4.3). This means that the turfgrass plants will be stressed more quickly in the St John and Palmerston North soils. Control of soil surface evaporation could, therefore, be more critical at an earlier stage of preparation for these soils as compared with the Ward and Kakanui soils. It also means that the grass plant has less water to extract from the soil before match day. Soils with lower levels of total available water may be advantageous where time for preparation is limited, such as with weekly club cricket.

TABLE 4.3 Volumetric water content at field capacity (FC), stresspoint (SP) and permanent wilting point (PWP), calculated total available water (TAW) and readily available water (RAW), and estimated times to depletion for the trial plots.

Pitch Soil	FC[3]	SP	PWP	TAW[2] (mm)	Time[1] (days)	RAW (mm)	Time (days)
Palmerston							
North	0.50	0.41	0.26	24	5.3	9	2.0
St John	0.54	0.42	0.30	24	5.3	12	2.7
Kakanui	0.61	0.46	0.31	30	6.7	15	3.3
Ward	0.71	0.55	0.38	33	7.3	16	3.6

Assumed

[1] Evaporative rate = 4.5 mm/day

[2] Effective rooting depth = 100 mm

[3] Field capacity measured approximately 24 hours after irrigation

Conclusions

1. The grass plant was shown to be water stressed for a large part of the preparation programme. For the soils studied, the stress point was reached 2-4 days after watering to saturation.

2. Maintenance of a moist soil surface during the early stages of preparation will reduce plant water stress and may provide a greater opportunity for prolonged evaporative water loss and plant water extraction to depth by preventing the development of a steep moisture gradient near the surface.

3. Permanent wilting point values corresponded to the minimum levels of soil moisture measured in the surface layer but the higher soil water contents at depth may reflect the reduced extent and effectiveness of the root system in the lower region of the soil profile.

4. The rate and extent of turfgrass transpiration and associated water loss from the pitch soil represents an area for further study.

5. By combining total available water with the rate of evaporative loss, it is possible to determine the minimum potential time required to reach match day soil dryness. For the soils studied this time interval was 5-7 days. This theoretical calculation can be modified to more closely approximate soil field behaviour by regular gravimetric water content sampling.

6. Soils with lower levels of total available water may be advantageous where time is a factor limiting pitch preparation e.g. weekly club cricket.

4.4 Soil Plasticity

A comparison of the upper and lower plastic limits and the range between them (plasticity index) for the pitch soils studied is given in Table 4.4.

Plasticity is an expression of soil consistence or workability when the soil is wet. Therefore, it could be expected that the Marton and Ward soils with higher plasticity indices (Table 4.4) would be more difficult to handle in the field than the Palmerston North and St John soils which have a lower plasticity indices, such as (Table 4.4). As they hold more water between the liquid and plastic limits, soils with greater plasticity values will be in a sticky condition for a longer period after watering to saturation. This has implications for scheduling of initial rolling operations (Section 4.5), and the use of machinery for physical treatment. Optimum rolling water contents (Table 4.5) are, in general, 3% to 4% lower than the plastic limits for the soils. Simply because a soil can be deformed and is not sticky, does not mean that rolling should begin. Care must also be taken not to vibra-mole soils of high plasticity when they are wet. Instead of the soil shattering effect which creates continuous macropores for deep rooting, single slots with glazed walls may be formed by the mole blade. Such channels will become water reservoirs and tend to re-open the following summer, resulting in visible lines through the pitch surface (Section 6.10).

Soil cohesion is related to plasticity. It could be expected that soils with higher plasticity would develop greater hydrogen bonding due to the greater attraction of the clay particles for remaining soil water as drying proceeds. Such soils may be characterised by harder surfaces when thoroughly dry. Further, they would be less likely to crumble or powder during a match. Comparison of A.S.S.B. (Table 5.1) and plasticity (Table 4.4) values for these pitch soils lends support to the theory that soils with lower plasticity indices have reduced binding strength on drying. In the field, the Palmerston North and St John soils have, respectively, shown a tendency for greater surface wear and crumbling at crack edges (Plates 4.1; 4.2).

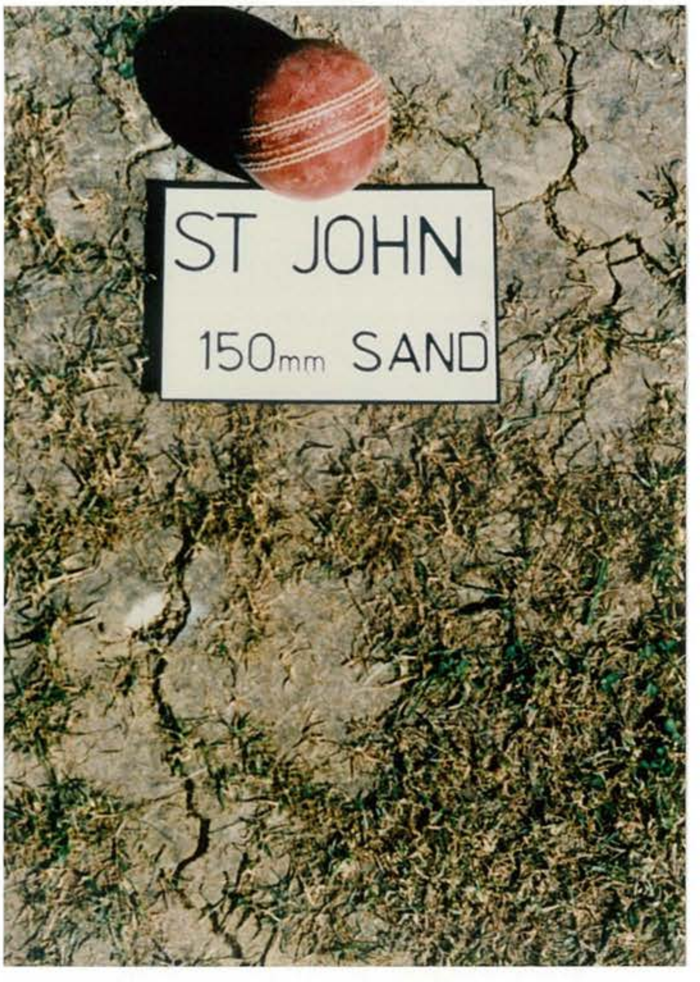


Plate 4.2 Minor to moderate (2-4 mm) cracking characteristic of the limited swelling St John soil and the development of soil crumbling at crack edges.

TABLE 4.4 Upper and lower plastic limits and plasticity indices for the pitch soils studied.

Pitch Soil	Plastic Limit	Liquid Limit	Plasticity Index
Palmerston North	24	28	4
Marton	25	41	16
St John	27	39	12
St John A	28	39	11
St John B	28	40	12
Kakanui	27	40	13
Ward	34	56	22
Redhill	55	63	8

Conclusions

1. Soils with higher plasticity indices could be more difficult to 'handle' in the field as they hold more water and will be in a sticky condition for a longer period after irrigation.

2. Soil plasticity influences the timing of rolling operations and physical treatments of the pitch soil.

3. Soils with lower plasticity indices may have reduced binding strength on drying which could indicate a greater tendency to wear during a match.

4.5 Proctor Compaction

The level of compaction able to be reached in a soil varies with moisture content. For each soil there is an optimum moisture content at which state of compaction or bulk density is maximised.

The maximum bulk density values and corresponding optimum water contents for the soils studied are shown in Appendices 4.1 - 4.6 and summarised in Table 4.5.

Ordinary Proctor test results represent the action of a light to medium roller in the field, while the Heavy Proctor test results relate to the use of a heavier roller (Appendix 4.7). These results can be used to schedule the timing of initial pitch rolling following irrigation, and to determine the roller mass to be used at different stages of pitch preparation.

Optimum soil moisture contents for the soils range from 21-34% (Table 4.5), with higher soil moisture values being recorded for soils with higher clay contents (Table 4.1). The value of 23% recorded for the Kakanui soil, which has swelling tendencies, is similar to the water content values recorded for non swelling and limited swelling soil types. This suggests that the optimum soil moisture content for rolling is influenced more strongly by clay content than by the types of clay minerals present in the pitch soil.

TABLE 4.5 Plastic limit water contents together with optimum water contents water content ranges and corresponding maximum bulk density values for Proctor compaction of the pitch soils studied.

		Ordinary Compaction			Heavy Compaction		
Pitch Soil	Plastic Limit (%)	Optimum Water content (%)	Water content range (%)	Max bulk density Mg/m^3	Optimum Water content (%)	Water content range (%)	Max Bul density Mg/m^3
Palmerston North	24	21	18-23	1.59	13	11-15	1.85
Marton	25	22	18-26	1.53	18	15-19	1.75
Kakanui	27	23	20-27	1.57	18	15-20	1.74
St. John	27	24	22-27	1.54	18	16-20	1.73
Ward	34	29	27-31	1.39	25	24-26	1.54
Redhill	55	34	31-36	1.38	30	28-32	1.53

While each soil has associated with it an optimum moisture content for most efficient compaction, Appendices 4.1 - 4.6 show that a moisture content range can be established within which compaction efficiency is not greatly reduced. The range of values (Table 4.5) provides a set of field working conditions for the groundsman.

The optimum moisture content values are 3-5% lower than the plastic limits for each soil (Table 4.5). An exception is the Redhill soil, where a wide discrepancy exists between plastic limit and optimum water content. Since the optimum water contents are lower than the plastic limits, there could be a tendency for the groundsman to roll at the plastic limit, with a resulting decrease in rolling efficiency.

By combining a knowledge of plant rooting depth, soil moisture content after irrigation (field capacity), optimum moisture content for Proctor compaction (Section 4.1) and the rate of water loss by evapotranspiration, it is possible to determine how long it will take to reach soil conditions suitable for most efficient soil compaction.

The time durations to reach the 'optimal rolling' water content for each soil are shown in Table 4.6. As discussed in Section 4.3, non-uniform soil drying with depth has not been accounted for and the procedure should, therefore, be fine-tuned by gravimetric water content sampling for each soil. The results, however, provide a useful estimate upon which scheduling of rolling operations can be based.

From Table 4.6 it can be seen that the time required to reach the optimal rolling water content ranged from 2 to 4 days for the pitch soils studied. There is a greater risk of high clay content and/or swelling type soils being rolled when they are too wet due to the potentially longer time required to reach suitable soil moisture levels.

TABLE 4.6 Volumetric water content at field capacity and optimal rolling and the estimated time to reach optimal rolling following irrigation.

Pitch Soil	Field Capacity[3]	Optimal Rolling Point	O.RAW[1] (mm)	Time[2] (days)
Palmerston North	0.50	0.39	11	2.4
St John	0.54	0.39	15	3.3
Kakanui	0.61	0.43	18	4.0
Ward	0.71	0.51	20	4.4

Assume

[1] Effective rooting depth = 100 mm

[2] Evaporative rate = 4.5 mm/day

[3] Field capacity measured 24 hrs after irrigation

As expected, the maximum bulk density and an optimum water content depend on the compactive effort used. For these soils an increase in the compactive effort (Heavy Proctor Test) increased the maximum bulk density or state of compaction by approximately 10%, but reduced the optimum water content at which this was achieved by 4-8% (Table 4.5).

This has important implications for the timing of heavy rolling. For the St John, Palmerston North, Kakanui and Marton soils, optimum water contents determined by heavy compaction (Table 4.5) approach those values required to produce a dry, hard pitch (Table 4.2). Therefore, the use of a heavy roller should be delayed until the latter stages of preparation, possibly a few days before the match begins. In comparison, on the Redhill and Ward soils a heavy roller should be used at an earlier stage of the preparation programme due to the higher optimal rolling water content (Table 4.5). Using heavy rollers at soil moisture contents greater than the optimal specified values is inefficient because little improvement in bulk density results on compaction (Appendices 4.1 - 4.6). Heavy rollers may also smear the soil surface and cause turf burial if the soil is too wet for the roller mass.

Higher values of bulk density with heavy compaction (Table 4.5), reflect an increase in soil shear strength and ultimately the potential to produce a denser, harder matrix with improved pitch bounce, pace and wear characteristics. It could also be expected that a heavier roller is more likely to overcome the cohesive resistances of soil particles and allow greater effectiveness of compaction. This may be of importance for aggregated swelling type pitch soils. It must be noted, however, that unless timing of rolling is correct, the benefits to be gained by using a greater compactive effect may not be realised.

Extra passes of any roller produce rapidly diminishing returns once adequate compaction is achieved. Measurement of soil density during pitch preparation, combined with a knowledge of maximum bulk density values obtainable with a given compactive effort (roller mass), will prevent rolling being carried on beyond a point where little or no increase in density is occurring. At this time roller mass can be increased or rolling for density improvement curtailed.

The effects of speed of rolling can be explained in terms of duration of effort. A rapidly applied effort may mobilise the viscous resistance in the water of some clay soils and is thus less effective than a slowly applied effort.

In the past there has been an attitude amongst groundsmen of the 'more rolling the better'. Certainly rolling is a key aspect of pitch preparation, but the efficiency of rolling, both from a soil and time viewpoint, is more important than the rolling duration. Monitoring of soil water content and bulk density permit scheduling of rolling operations to best effect, and ultimately the production of a superior pitch.

Conclusions

1. For each soil there is an optimum moisture content range within which compaction (bulk density) can be maximised in the field.

2. Results of this study suggest that optimum soil moisture content for rolling is influenced more strongly by clay content than by the types of clay minerals present in the pitch soil.

3. Optimum moisture contents are generally lower than plastic limits for each soil which could mean there is a tendency to roll when the soil is mouldable, but too wet for greatest compaction efficiency. This is especially applicable to high clay content and/or swelling type soils.

4. By combining a knowledge of plant rooting depth, soil moisture content after irrigation, Proctor compaction values and evaporative demand, it is possible to specify the time needed to reach soil moisture conditions suitable for most efficient compaction. Fine-tuning can be achieved by gravimetric water content sampling.

5. Increasing the compactive effort (roller mass) increases the bulk density but reduces the optimum water content for compaction. On the Palmerston North, St John, Kakanui, and Marton soils, the use of a heavy roller should be delayed until the latter stages of pitch preparation. For the Ward and Redhill soils it can be used at an earlier stage because the optimum rolling water content is significantly higher than that required at match day.

7. Measurement of soil bulk density during preparation, combined with a knowledge of maximum bulk density obtained by a given compactive effort (roller mass), will prevent rolling being carried out beyond a point where soil compaction (bulk density) is not increasing.

8. Rolling is a key aspect of pitch preparation but quality not quantity of rolling is important both in terms of pitch performance and efficient use of management resources.

4.6 Empirical Tests

Four simple empirical tests were used to determine the pitch potential of a selection of soils (Section 4.1).

The St John, Kakanui, and Marton soils all passed the pinch test with no cracks resulting when a ball of clay was formed into a disc. The Redhill soil, however, cracked extensively around the perimeter 20 mm when a disc was formed so did not pass this test.

All soils studied, with the exception of the Redhill soil, could support their weight with very little or no visible stretching or cracking occurring. The Redhill soil broke immediately. Similarly, it broke with little or no stretching in the elongation test. The other soils formed 'necks' of varying length (Marton, 130 mm; Kakanui, 155 mm; St John, 110 mm), and breaks were sudden and clean.

In the soaking test, the Redhill soil completely disintegrated within 30 minutes while the Kakanui and St John soils collapsed between 24 and 48 hours. The Marton soil remained intact and stable after 2 days. On the basis of these tests it could be concluded that the Marton, St John, and Kakanui soils have soil textures and clay mineral compositions which provide an acceptable level of soil cohesion. In comparison, the Redhill soil did not pass any of these simple tests, and could be considered potentially unsuitable for pitch use (soil cohesion is an important soil property).

Conclusions

1. While these empirical tests do not provide precise numerical results, they give an indication of the properties of the potential pitch soil. The results may be used as a guide when screening soils for more elaborate and comprehensive soil tests.

2. More importantly, the simple nature of these tests makes them extremely useful for groundsmen who often do not have access to laboratory testing facilities and equipment.

4.7 Shrinkage of Pitch Soils on Drying

Change in soil volume with decreasing water content, manifested in the field by the tendency of many soils to crack on drying, has important practical implications for pitch management and playability (Section 1.3 (ii); Section 6.7).

(a) Free swell test

On the basis of evaluation of cracking behaviour of the soils in the field (Section 6.10) and comparison with measured free swell values, classification system has been developed to provide a guideline for potential cracking behaviour of pitch soils (Table 4.7).

Table 4.7 A comparison of free swell values with measured pitch cracking on drying in the field.

Free Swell (%)	Pitch Cracking Potential
≤ 15%	Little or no tendency to crack (hair-line)
16-25%	Cracking hair-line or minimal (1-2 mm)
25-50%	Cracking moderate and acceptable (1-4 mm)
> 50%	Development of extensive to excessive cracking (5-8mm)

The simple nature of this test could make it very useful for providing a general assessment of the potential cracking capacity of a soil in the initial determinative stages of soil suitability and pitch soil selection.

(b) Volume change

Volume change on drying, taking into account the whole soil rather than just the clay and fine silt fractions, is important. The contribution of coarse silt and sand to soil texture, and therefore volume change, is significant (Table 4.1) and modifies many of the properties conferred by the clay fraction.

Whereas the average percentage changes in volume ranged from 8% to 20%, the free swell test values ranged from a low of 15% for the Palmerston North soil, to a high of 83% for the Kakanui soil (Table 4.8).

The potential shrinkage capacity ranking order established for the soils by the free swell test was modified when volumetric shrinkage was determined. The higher shrinkage capacity of the Marton and Redhill soils, and reduced shrinkage potential of the Kakanui soil may be explained by reference to clay content. While the clay minerals present in the Marton and Redhill soils are predominantly of the non swelling type (Table 2.1), the high clay contents of these soils mean that the properties of the clay fraction are more strongly expressed. In comparison, the Kakanui soil has a lower clay content than the Ward soil (Table 4.1) so the development of swelling and shrinking properties conferred by the smectite clay minerals (Table 2.1) is reduced. As a result, cracking on drying in the field of the Kakanui soil may not be as extensive as the free swell test would suggest. The similar cracking behaviour observed for the Ward and Kakanui soils in the field (Section 6.7) supports this claim.

The shrinkage capacities for soil mixes at a ratio giving maximum compressive strength (Section 5.5) were also determined. Results

TABLE 4.8 Percentage soil shrinkage on drying as measured by free swell, change in volume, and linear shrinkage.

Pitch Soil	Free Swell %	Change in Volume %	Linear Shrinkage %
Palmerston North	15	8	3
Redhill	19	20	7
Marton	23	19	7
St John A	30	13	6
St John B	30	n.d.	n.d.
St John	35	13	5
Ward	60	20	12
Kakanui	83	18	11
Palmerston North[86]	n.d.	13	n.d.
St John/Marton[1]	n.d.	13	n.d.
St John/Redhill[2]	n.d.	18	n.d.

[1] 1:2 Ratio

[2] 1:2 Ratio

n.d. = not determined

presented in Table 4.8 indicate that shrinkage values for a soil mix are similar to those values defined for individual soils of the mix. It could be expected that shrinkage capacity will be modified by the ratio of individual soils in the mix. Therefore, it is hypothesised that the performance of a swelling soil such as the Ward may be improved by mixing with a compatible non swelling type. This needs further investigation.

(c) Linear Shrinkage

Linear shrinkage as a one-dimensional measurement of soil shrinkage was determined and the potential shrinkage capacity ranking order was found to be similar to that established by the free swell test (Table 4.8). Differences between linear shrinkage and measured volume changes were probably due to differences in soil texture of test samples.

Conclusions

1. While there are differences in observed shrinkage capacity of the soils depending on the shrinkage test used, the values obtained permit a numerical estimate to be placed on soil shrinkage potential.

2. Provided testing methods are standardised, the results given for the soils studied can be used as a reference for development of soil selection programmes.

3. Soil shrinkage, manifested by cracking development in the field, is an important factor influencing playability and management of the cricket pitch. Soil selection must ensure soil shrinkage potential is compatible with the climatic conditions, pitch use and management resources available.

4. The free swell test is simple and easy to carry out and provides a general assessment of potential soil cracking capacity. It offers considerable value to the groundsman and researcher in the initial stages of soil suitability and pitch soil selection.

CHAPTER 5: SOIL BINDING STRENGTH - THE ADAMS STEWART SOIL BINDING TEST (A.S.S.B. TEST)

5.1 Method - Practical Procedure for A.S.S.B. Test

The method for assessing soil binding strength was adapted from that specified by Stewart and Adams (1969) and described by Dury (1982a).

(i) Procedure - Standard A.S.S.B. Test

1. Air dry soil samples were sieved (2 mm) and 15-20 ml of water was added per 50 g of soil (according to soil texture). Each soil was mixed thoroughly using finger pressure and smearing on a glass surface, to break down aggregation.

2. Water content was adjusted to between the plastic and liquid limits for each soil and samples were placed in sealed containers to equilibrate for 24 hours.

3. After equilibration, soil water content was adjusted by addition of water if too dry, or removal of excess water with filter paper if too wet.

4. Samples were rolled into cylinders approximately 20-25 mm in diameter and the cylinders were cut into 10 mm sections.

5. Individual sections, of mass 13-14 g, were weighed accurately to one decimal place.

6. Sections were formed into round balls, avoiding folds. A drop of water was added and the soil reworked if cracking occurred. Balls were rounded off by rolling firmly between the palms of the hands for at least 45 seconds, to form near-perfect spheres of 20-25 mm diameter with shining surfaces and no cracks.

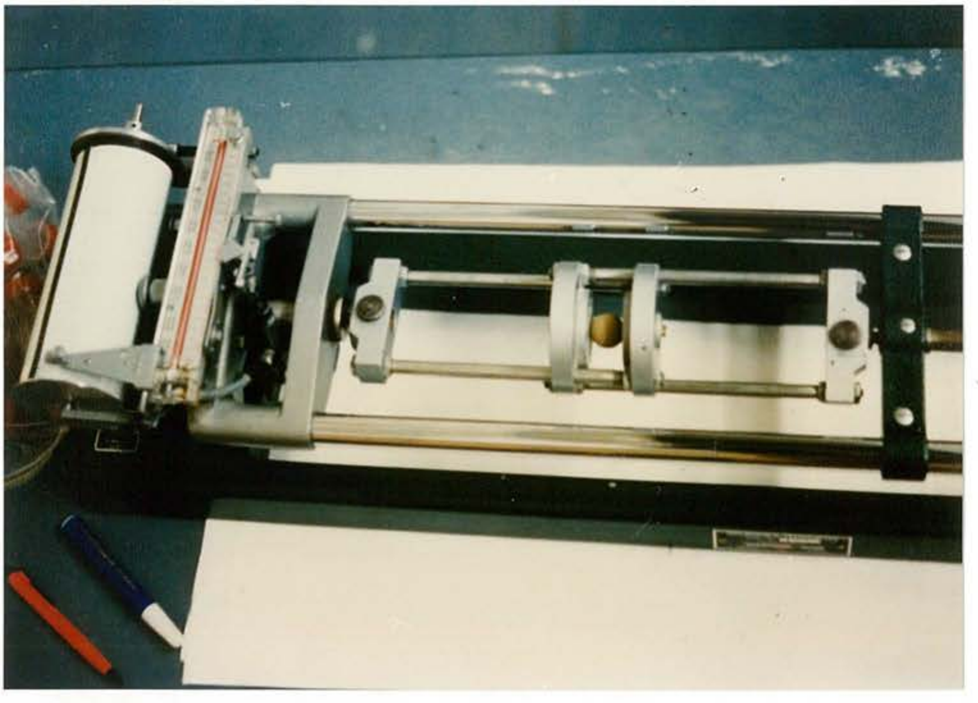


Plate 5.1 The Hounsfield Tensometer used to measure motty soil binding strength.

7. Motty diameter was measured using vernier calipers accurate to 0.1 mm.

8. Standard air drying was carried out at a constant temperature of 20°C away from direct sunlight. Rapid sun drying occurred at temperatures of 25-30°C in direct sunlight. Equilibration was complete in 5 days.

9. The compressive force required to shatter soil spheres was determined using a Hounsfield Tensometer with a 0-1.0 kN scale and a 2.2 kN weight bar (Plate 5.1).

(ii) Procedure - Modified A.S.S.B. Test

The modified A.S.S.B. test procedure (Adams, 1985), was similar to that specified for the standard motty test but to make a motty for testing, a ball of each soil was dropped onto a clean surface to create a flat face. After moistening the two faces with a drop of water, they were pushed together and a motty formed. Final motty masses ranged from 12-15 g and a standard 5 day air drying regime was used.

5.2 A.S.S.B. (Motty) Test Values

Compressive strength or binding strength values for the soils studied ranged from a low of 28 kg for the Palmerston North soil to a high of 100 kg for the Kakanui soil (Table 5.1). On the basis of the standards developed by Stewart and Adams (1968), most of the soils studied would be classed as suitable only for club pitches (45-70 kg breaking strength). The Naike soil, with an A.S.S.B. value of 78 kg is the only soil which meets the binding strength requirements for use on first class and international cricket pitches (70-95 kg breaking strength). Two soils, the Palmerston North and Redhill, are unsuitable for pitch use due to their low compressive strength values ($<$ 45 kg breaking strength), while two soils, the Kakanui and Port Albert, are classified as being too strong for pitch use ($>$ 95 kg breaking strength). These findings

TABLE 5.1 **Binding strength (A.S.S.B.) values and end point gravimetric water contents for the pitch soils studied.**

Pitch Soil	A.S.S.B. Value (kg)	End-point Gravimetric Water content (%)
Palmerston North	28 ± 4	2.5
Redhill	34 ± 1	9.0
Palmerston North[86]	40 ± 1	4.7
St John A	41 ± 2	3.4
St John B	43 ± 2	4.5
St John	51 ± 4	4.3
Ward	65 ± 6	5.3
Marton	66 ± 2	5.0
Naike	78 ± 6	14.0
Kakanui	100 ± 7	5.5

The A.S.S.B. test may not provide a foolproof indication of pitch playability but it does give guidelines for potential soil performance. Soils with compressive strength values of 45-70 kg could be more easily prepared to produce pitches in the easy-paced to fast category, although an increase in pace beyond this point may not be achieved without a change in soil type. In practice, soils in this category are more likely to consistently perform at potential pace. On the other hand, pitches prepared on swelling type soils with higher binding strength values have the potential to be fast paced, but require more exact preparation to achieve this potential.

More significantly, the motty test provides valuable information about the potential of a pitch soil to wear during a match. Generally, soils with strength values below 45 kg have a tendency to wear excessively around the crease area as a result of player activity on the pitch. This problem has been apparent at Fitzherbert Park in the past due to the low binding strength of the Palmerton North soil. Edges of cracks may also crumble if the grass cover is not uniform and bare patches are present on the pitch. Plate 4.2 shows surface crumbling at crack edges on the St John soil, the binding strength value of which is only moderate (Table 5.1). With such soils, it may be necessary to increase the clay content, a practice which has been carried out successfully at Fitzherbert Park by the groundsman to reduce pitch wear significantly during the 1987/88 season (Plate 4.1). The tendency of a soil to powder and crumble around the area of the stumps can also be reduced by increasing the soil moisture content in this region (pers. comm. C. Renwick).

The problem of pitch wear is exacerbated by poor management practices resulting in under-preparation of the pitch. These include shallow drying, insufficient or poorly-timed rolling, poor grass cover or development of soil layering. This under-preparation was evident in the England *vs* New Zealand one-day match at Eden Park (March 19, 1988) where the ball went through the surface of the pitch (Plate 5.2). This was due to insufficient soil hardness as a result of higher than desirable pitch soil moisture levels (Section 6.8).

Plate 5.2 Surface deformation caused by ball impact with the pitch during the New Zealand *vs* England one-day match, March 19, 1988 at Eden Park, Auckland.

conflict with those of Murphy (1985), who found that the majority of soils used on first class pitches in New Zealand had breaking strengths of 70-90 kg. An explanation for the anomaly may be a discrepancy in motty size, as discussed in Section 5.3.

Stewart and Adams proposed that the A.S.S.B. test could be used to predict potential pace of pitch soil materials. In the present study, however, there was a poor relationship between binding strength values and playability data collected (Chapter 6), suggesting that the A.S.S.B. value alone is not a reliable indicator of pace and bounce. Figure 5.1 shows bounce test values predicted by the A.S.S.B. rating and compares these values with rebound bounce test values recorded on the trial plots during the second preparations of 1986/87 and 1987/88. While a closer relationship exists between potential and actual rebound bounce for swelling type soils, the potential bounce height for non swelling type soils is underestimated due to the lower compressive strengths.

As expected, the swelling type soils produced soil spheres of greater compressive strength due to the nature of the clay minerals present (Section 2.1), and the higher clay contents (Table 4.1). The greater compressive strength occurred despite higher motty end point gravimetric water contents (Table 5.1).

While the higher binding strength values of the swelling type soils indicate a greater potential for production of a faster, harder pitch, this potential soil strength is often not fully realised in practice. Management factors often prove over-riding, to the extent of nullifying the desirable properties of such soils. Difficulties with drying swelling soils evenly to depth, and controlling the rate and extent of associated cracking means that soil hardness is in many instances not fully developed. In comparison, non swelling type soils hold less water at the -1 bar and -15 bar matric potentials (Table 4.2) and develop manageable surface cracking on drying. Soil hardness realised in the field (Section 6.4) more closely approximates potential soil hardness and rebound bounce and pace are often superior.

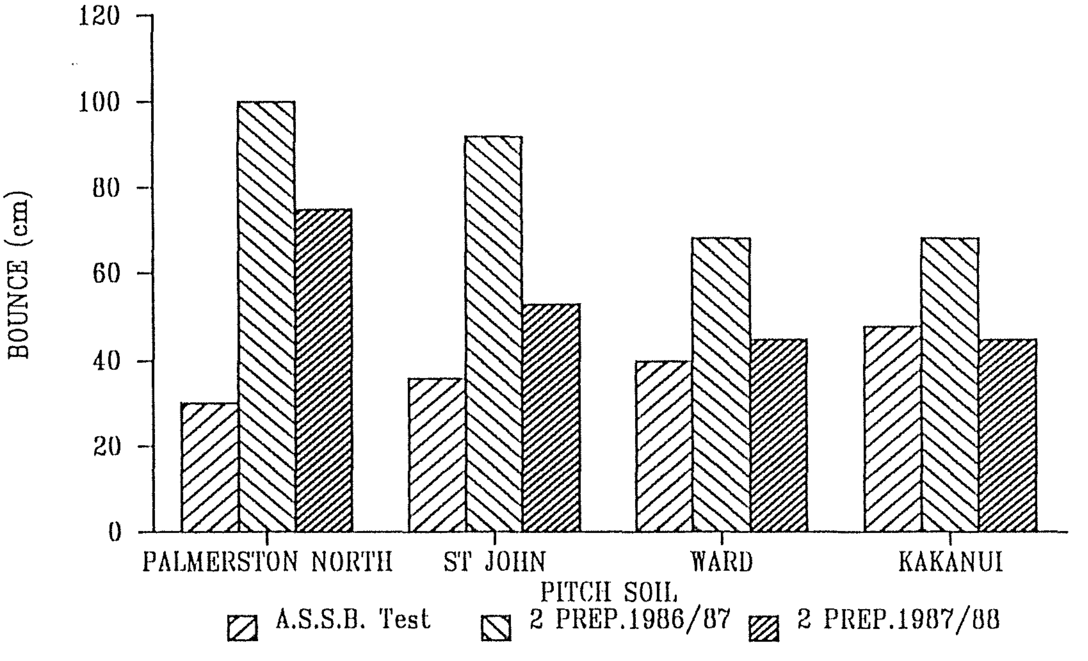


Figure 5.1 Comparison of rebound bounce predicted by the A.S.S.B. test with average bounce measured on the trial plots at Fitzherbert Park during the second preparations of 1986/87 and 1987/88

Conclusions

1. Binding strength values for many of the soils in this study did not meet the criteria specified by Stewart and Adams (1968) for first class and international pitch use.

2. Rebound bounce predicted by the A.S.S.B. test was not closely related to bounce test values measured on the trial plots. This difference was greater for non swelling and limited swelling soils with lower A.S.S.B. values.

3. By virtue of higher binding strength values, swelling soils have a greater potential to produce fast, hard pitches. In practice, however, management factors often combine to prevent such potential being developed.

4. The chemical and physical properties of non swelling and limited swelling soils indicate that they are more easily managed. As a result, soil hardness achieved in the field more closely approximates potential hardness defined by the A.S.S.B. test.

5. Motty test values provide valuable information about the potential of a soil to wear during a match. Soils with strength values less than 45 kg may wear excessively.

5.3 Motty Size

Stewart and Adams (1968), standardized the size of soil spheres used in the A.S.S.B. test at approximately 20 mm diameter when moulded ready for drying. These motties could normally be formed from approximately 12 g of dry soil.

In the present study, it was found that wetted soil with a mass of 13-14 g (average mass 13.5 g) allowed production of soil spheres 23-26 mm in diameter (average diameter 25 mm) when moulded ready for drying. Using these guidelines it is possible to develop and

Plate 5.3 Four sizes of soil spheres used to determine the influence of motty size on binding strength and motty volume change on drying.

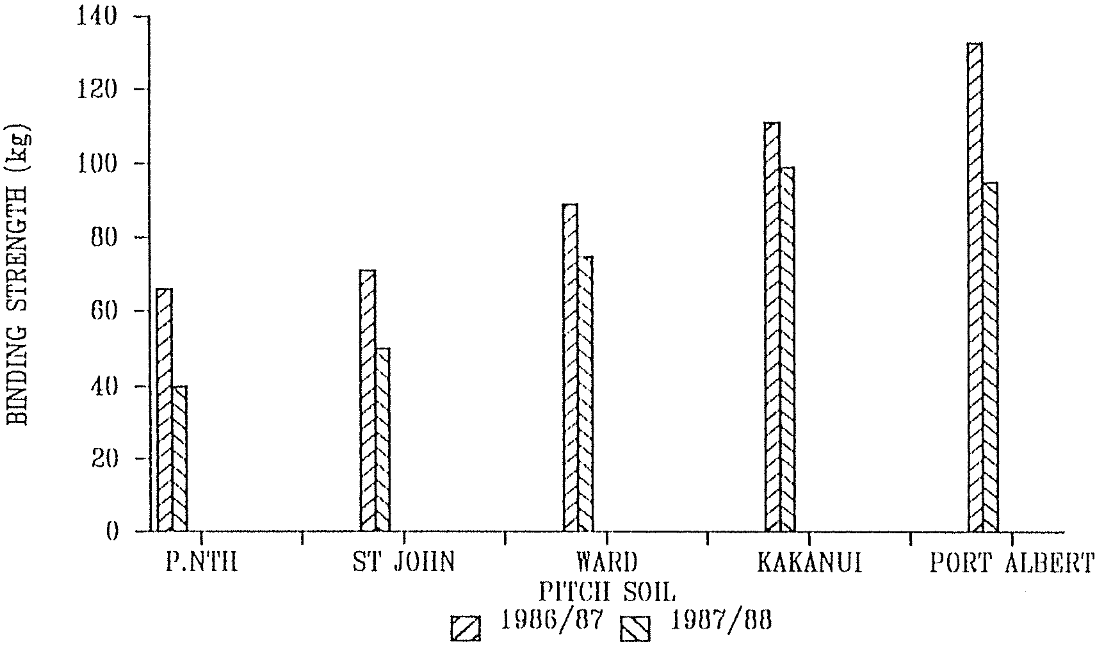


Figure 5.2 Comparison of motty binding strength values determined by McAuliffe *et al.*, (1987) with A.S.S.B. values measured during the 1987/88 testing period

maintain a high level of uniformity for motty size. This in turn resulted in low binding strength variation of motty replicates (Table 5.1). Moreover, this standardisation was not affected by different operators performing the A.S.S.B. test.

Preliminary investigations indicated that changes in motty mass, resulting in relatively small changes in motty diameter, could have a significant effect on motty strength (Table 5.2). It was thought that this size-strength relationship may explain the apparent anomalies existing between the findings of McAuliffe *et al.,* (1987), and the 1987/88 A.S.S.B. test results for similar soils (Figure 5.2). Strength values generated in the 1986/87 testing programme were greater (10-40%), but motty diameter and mass were not recorded at this time.

A more detailed investigation was carried out to study the effect of motty size and mass on compressive strength. This study covered four soils, representing both swelling and non swelling types. Four size-mass treatments were used:

(a) 10.1 g mass; 22.8 mm diameter
(b) 13.5 g mass; 24-8 mm diameter
(c) 18.2 g mass; 26-0 mm diameter
(d) 21.4 g mass; 27.10 diameter (Plate 5.3)

Figures 5.3a and 5.3b show a linear relationship between (a) motty diameter and compressive strength, and (b) motty mass at time of making and compressive strength on drying, for both non swelling and swelling soil types.

In general, as soil mass and diameter increase so does compressive strength. Nevertheless, for the swelling type soils studied, this effect is reduced or eliminated beyond the 18.2 g; 27-28 mm diameter group. This suggests that beyond a certain point, motty strength is not affected by size or mass for swelling soils. Standardisation of motty size may not be as critical for these soils. This may explain why the discrepancy for swelling type soils studied in the 1986/87 and 1987/88 programmes is less than for the non swelling types (Figure 5.2).

TABLE 5.2 **A preliminary investigation of the influence of increased motty diameter on motty compressive for the pitch soils.**

Pitch Soil	Increase in motty diameter[1] (%)	Increase in motty compressive strength[2] (%)
Kakanui	15	25
Redhill	20	28
St John	13	29
Marton	14	30
Ward	26	37
St John B	24	46

[1] As a percentage of standardised motty diameter (25 mm)

[2] As a percentage of compressive strength for standardised normal air dry motty test

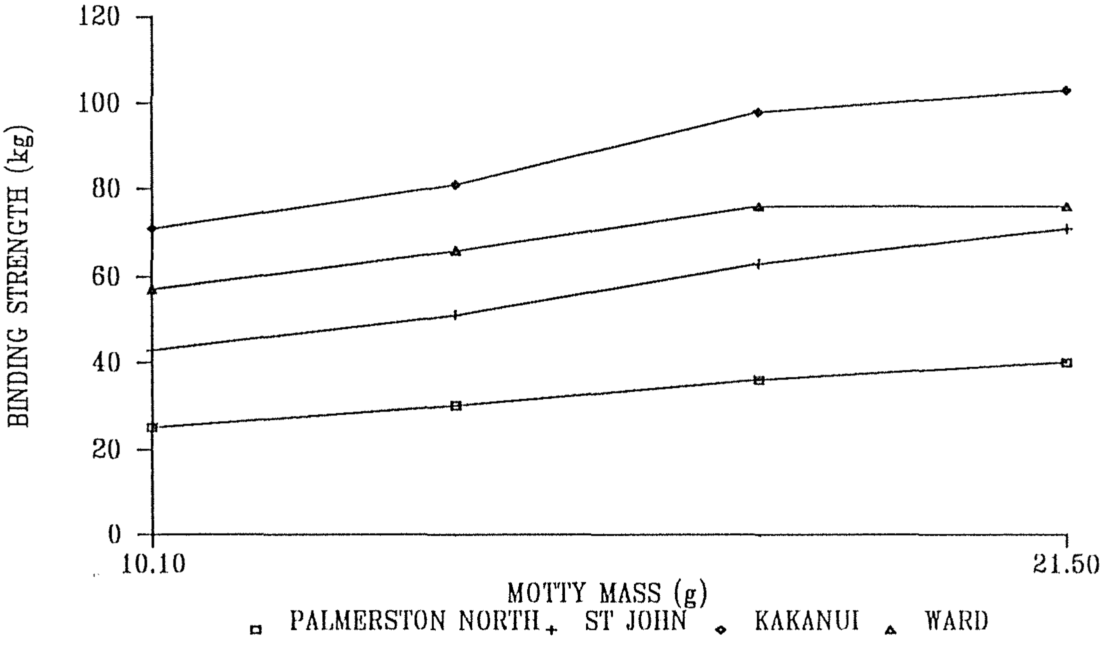


Figure 5.3a The influence of increasing motty diameter on motty binding strength

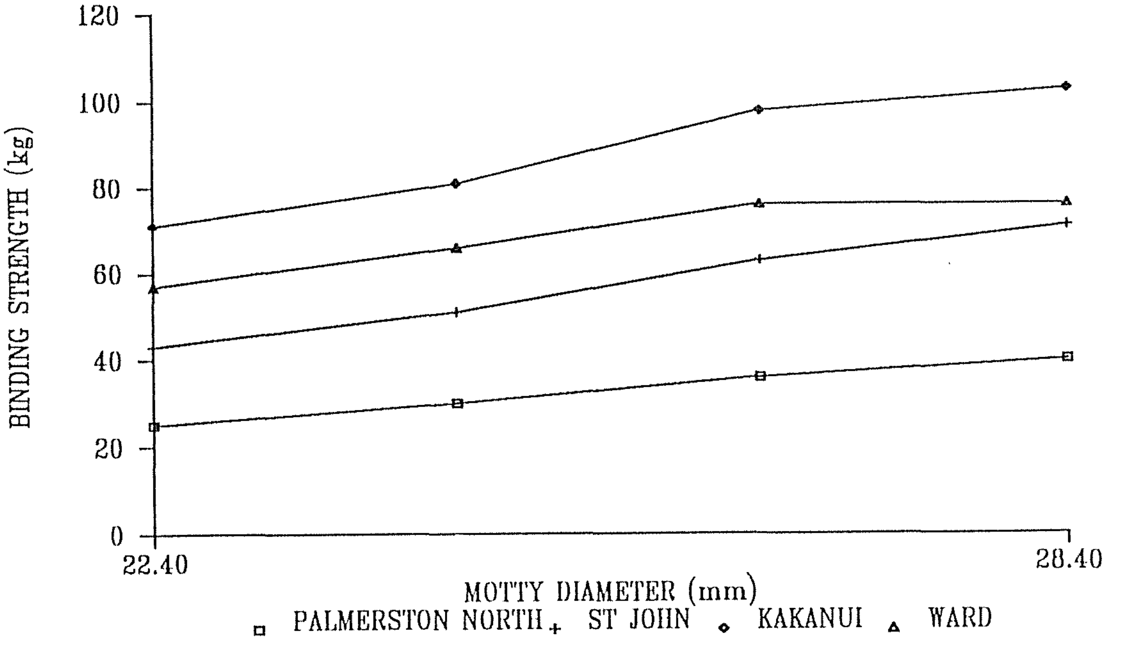


Figure 5.3b The influence of increasing motty mass on motty binding strength

Further support for this motty size-strength relationship is provided by comparison of a soil tested at Massey University with that tested at the New Zealand Turf Culture Institute (NZTCI). Table 5.3. shows that motty size was carefully monitored at Massey University and the corresponding degree of variation between soil spheres was reduced. Soil spheres manufactured at the NZTCI were, on average, 5% larger in diameter and had an average compressive strength 23% greater than those made at Massey University. This corresponded to absolute values of motty compressive strength of 101 kg and 78 kg respectively. Differences in compressive strength may also be attributed, in part, to the lower average end point gravimetric water content, of the NZTCI produced motties (Table 5.3). Nevertheless, unless motty size is standardised accurately, comparison of A.S.S.B. values between testing stations has only limited value. Furthermore, when undertaking the A.S.S.B. test, careful and specific size definition is essential to prevent misleading conclusions being drawn. To eliminate this problem it is proposed that the A.S.S.B. test procedure be amended to specify motty size be measured accurately using vernier calipers and the size recorded be reported with A.S.S.B. test results.

Conclusions

1. In this study, wetted soil with a mass of 13-14 g (average mass 13.5 g) allowed production of soil spheres 23-26 mm in diameter (average diameter 25 mm) when moulded ready for drying. (Both mass and diameter of soil spheres was measured accurately).

2. Size standardisation resulted in motty size uniformity and low motty replicate binding strength variation.

3. A linear relationship existed between (a) motty diameter and compressive strength and (b) motty mass at time of making, and compressive strength.

4. As soil mass and diameter increased so does compressive strength. For swelling type soils studied, this effect was reduced or eliminated beyond a certain motty diameter.

TABLE 5.3 Comparison of soil spheres produced at Massey University and the New Zealand Turf Culture Institute (NZTCI) with regard to motty size, mass, compressive strength and end point gravimetric water content on drying for the Naike soil.

Testing Station	Motty Mass (g)	Motty Diameter (mm)	Compressive Strength (kg)	End Point Gravimetric Water Content (%)
Massey University	13.6	21.5	88	14.1
	13.7	21.8	79	13.5
	13.3	21.5	75	14.0
	13.8	21.6	71	14.4
Average	13.6 ± 0.2	21.6 ± 0.1	78 ± 6.3	14.0
NZTCI	-	23.1	72	11.8
	-	22.7	100	11.4
	11.9	22.0	92	12.1
	12.5	23.6	116	11.7
	14.1	25.1	127	11.2
Average	12.8 ± 0.9	23.3 ± 1.0	101 ± 19.1	11.6

5. Motty size should be reported along with A.S.S.B. test values.
6. Without size standardisation, data generated by different testing stations must be compared with care to prevent misleading recommendations being made.

5.4 Rate and Extent of Motty Drying

Stewart and Adams (1968), specified a standard five day period to enable soil spheres to dry out until equilibrium in an atmosphere at 70% relative humidity (approximately air dry) is reached.

No research has quantitatively determined the rate of motty drying or investigated its effect on soil compressive strength. In view of this, the influence of rate of motty drying was investigated using two soils (McAuliffe *et al.,* 1987). The standard 5 day air dry procedure was used as a control, and comparisons were made with a rapid sun drying treatment. For both the soils studied, rapid sun drying produced a motty of lower strength (Figure 5.3), although in the case of the Palmerston North soil this may have been due to the higher end point motty water content. The reduced strength of the Ward soil with the rapid sun drying treatment may be due to development of microcracks within the motty.

In 1987/88 a more comprehensive study of the rate and extent of motty drying was initiated. Gravimetric water content of soil spheres was measured daily and related to compressive strength. Five day rapid sun drying and normal air drying treatments were used. A comparison of Figures 5.4a and 5.4b with Figures 5.5a and 5.5b shows that the rate of motty drying was faster for the sun drying treatment. The gravimetric water content of sun dried soil spheres approached an equilibrium value by the end of day 2, whereas this point was not reached with the normal air drying treatment until the end of day 3. For both drying regimes there was little further motty water loss on days 4 and 5. It was also found that the sun dried soil spheres had slightly lower end point gravimetric water contents (Figures 5.4a, b; and 5.5a, b).

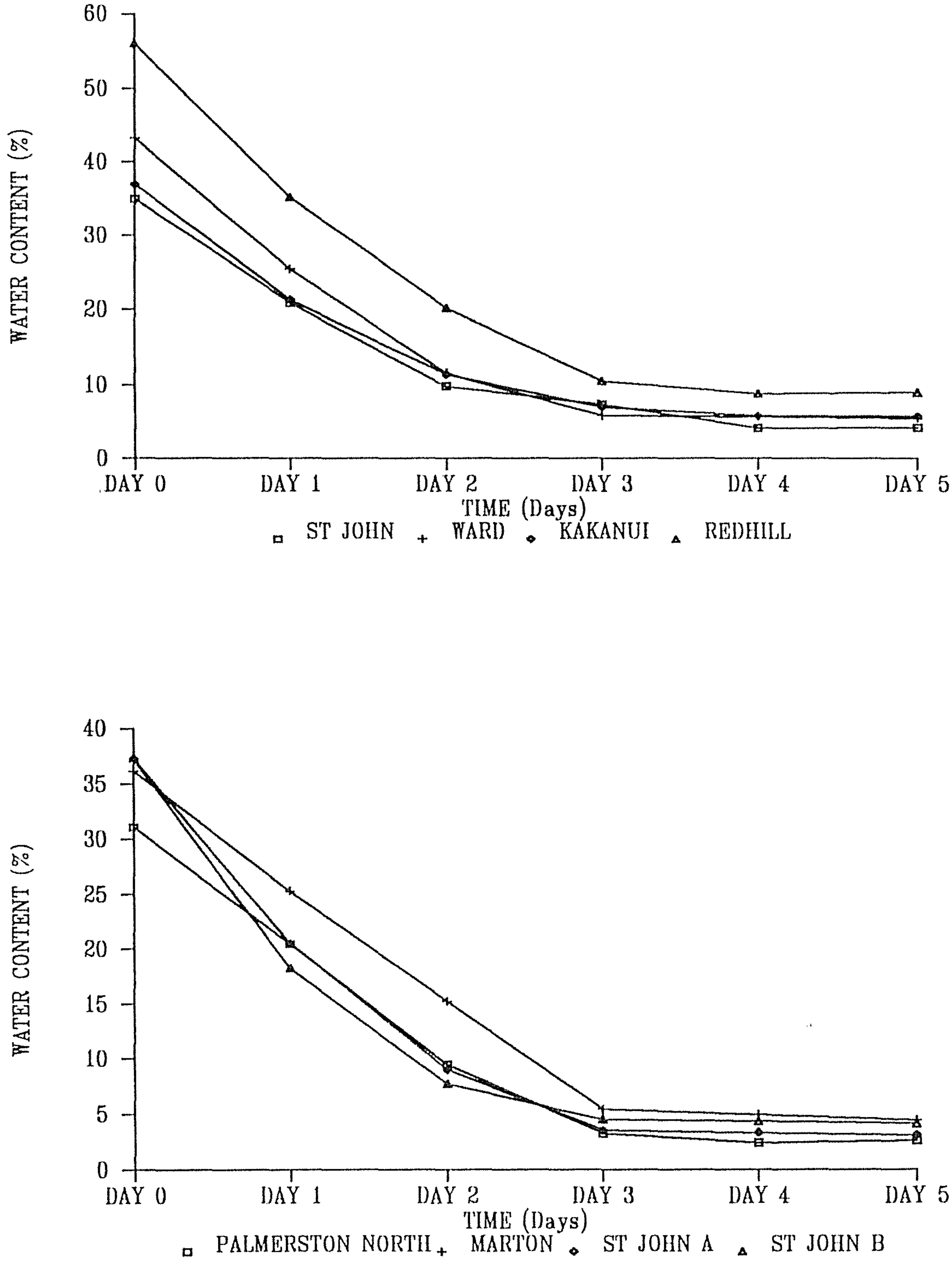
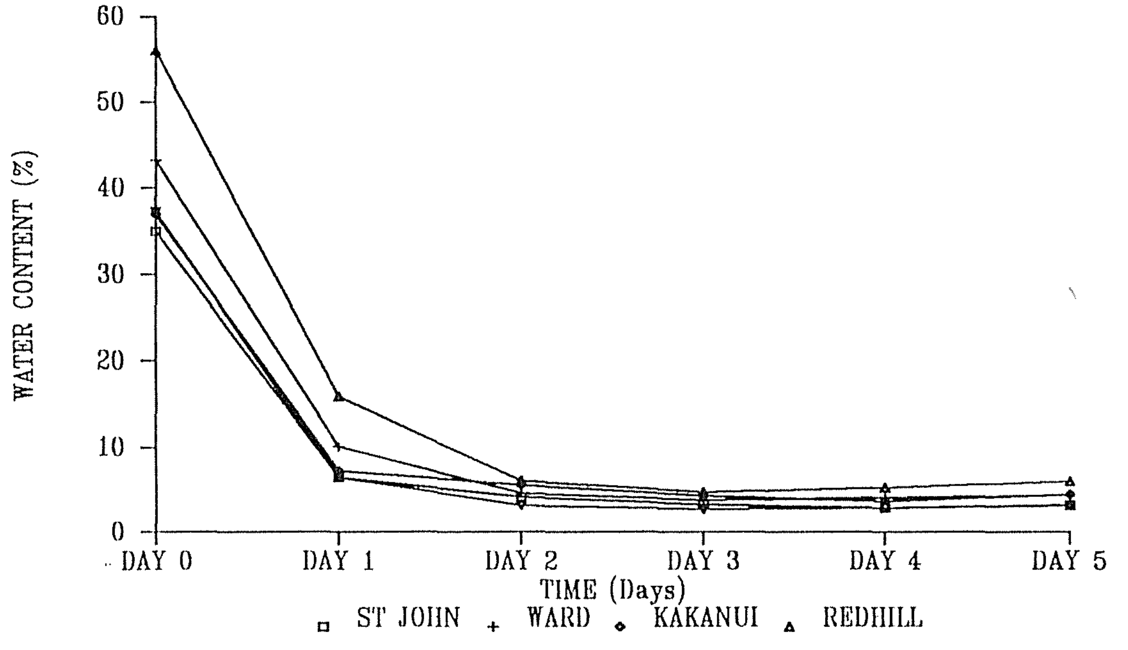


Figure 5.4a,b The rate and extent of motty drying during the five day A.S.S.B. test for a standard air drying treatment



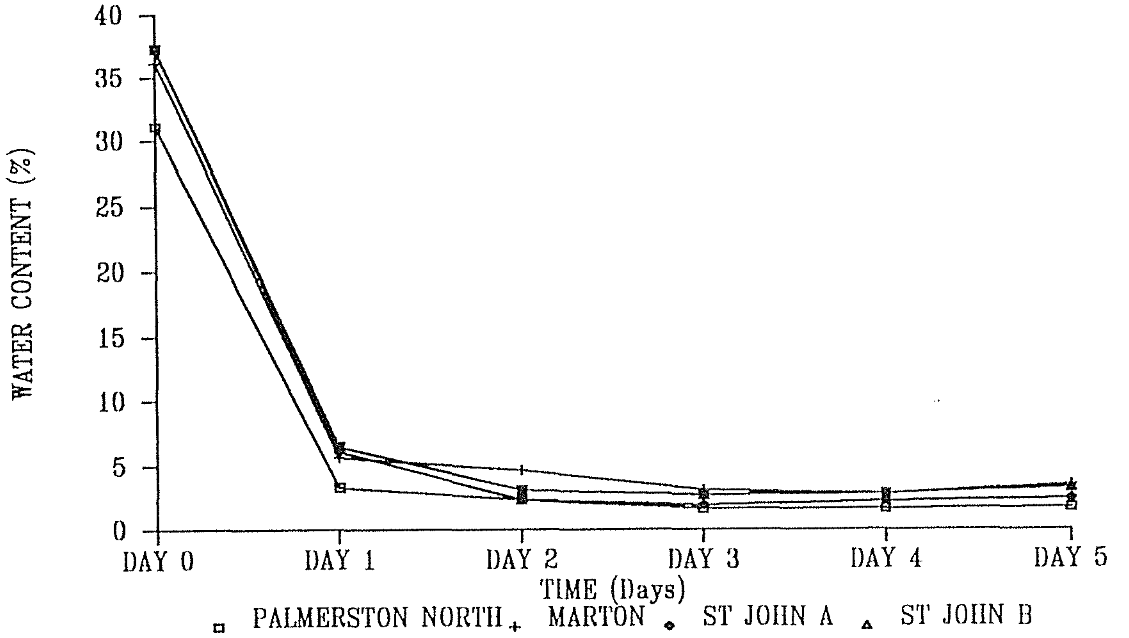


Figure 5.5a,b The rate and extent of motty drying during the five day A.S.S.B. test for a rapid sun drying treatment

In general, soils with higher clay contents and/or swelling type clay minerals held more water at the start of drying and had higher end point gravimetric water contents. The pattern of water loss on drying was generally similar to those soils containing non swelling minerals and/or lower clay contents under normal air drying conditions. It appeared that for the sun drying treatment (Figures 5.5a; 5.5b), the influence of clay type and clay content on the extent and rate of motty drying was reduced.

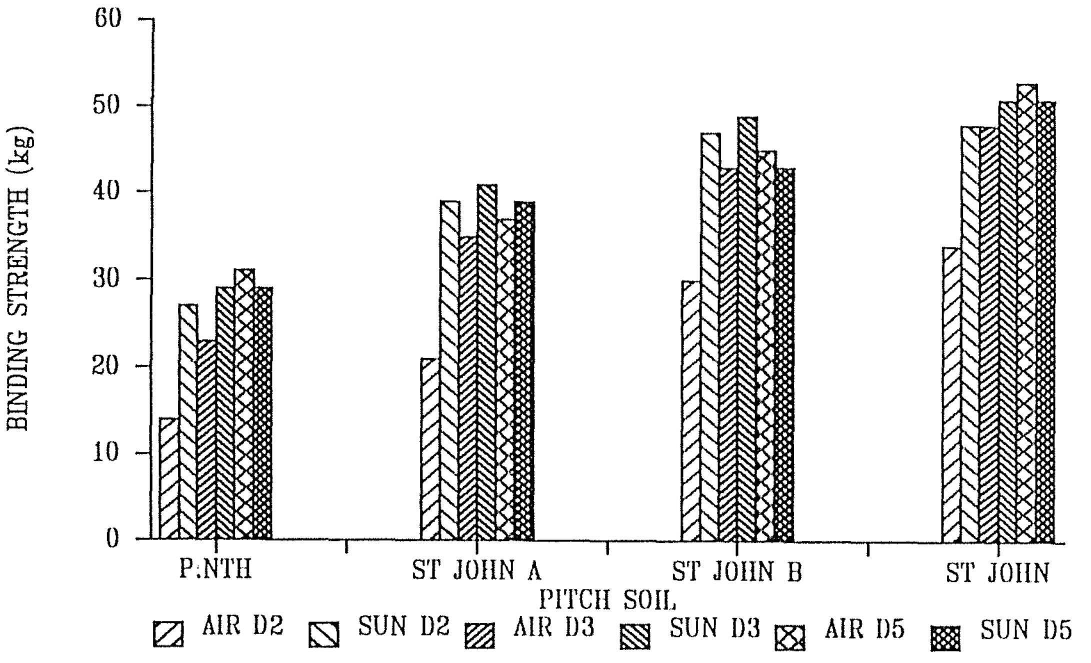
It follows that sun dried soil spheres had higher compressive strength values on day 2 as a result of lower gravimetric water contents. Figure 5.6a and 5.6b show that this effect was largely overcome by day 3 when air dried spheres approached equilibrium water content. By day 5 there were no significant differences in motty compressive strength between the drying treatments. The results suggest that the rate of motty drying may have little or no effect on the recorded compressive strength given a 5 day drying period. While motty water content, and therefore strength, may vary within this period, the time frame allows for variable rates of soil drying.

End point gravimetric water content should, however, be reported together with compressive strength values in case equilibrium water content has not been reached during the 5-day drying period. This will prevent misleading conclusions being drawn when results for different soils and from different testing stations are compared.

The differences in compressive strength recorded for the two drying treatments in the 1986/87 study are at odds with these findings. These differences may be explained by the higher end point gravimetric water contents of the sun dried soil spheres, or by some other factor such as motty size.

Conclusions

1. The rate of motty drying may have little or no effect on the recorded compressive strength given a 5 day drying period.



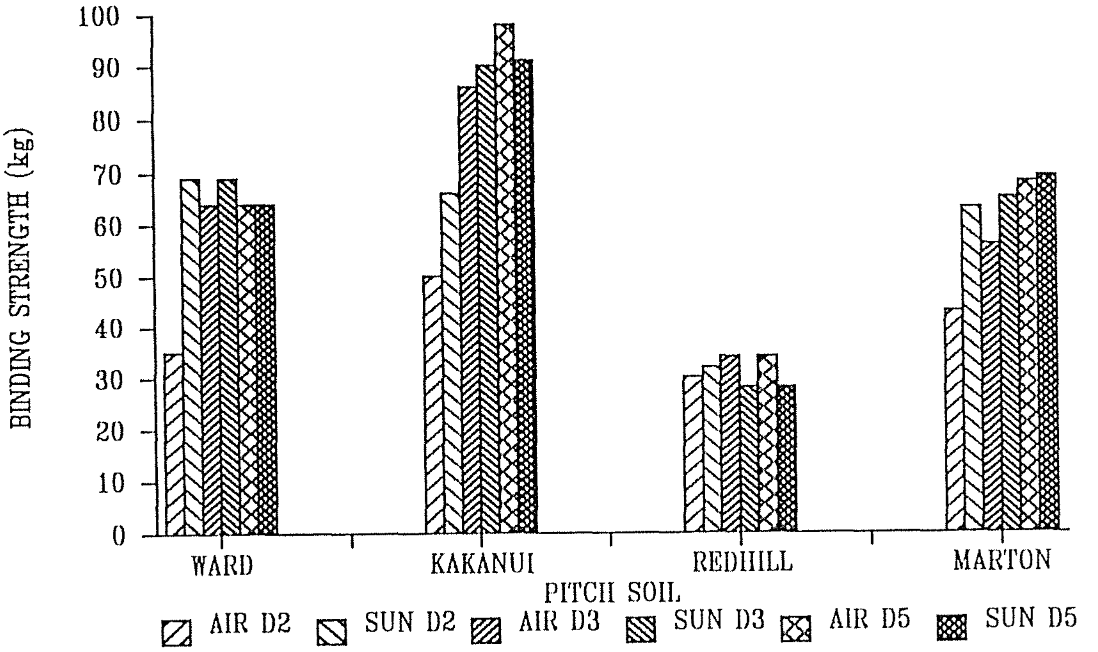


Figure 5.6a,b A comparison of motty binding strength development during a five day A.S.S.B. test for standard air drying and sun drying treatments

2. The extent of motty drying is of particular importance and end point motty water contents should be recorded along with A.S.S.B. test values to allow comparison of results between testing stations.

5.5 Assessing Soil Compatibility for Topdressing and Mixing

The original St John soil used in Auckland was of limited supply and consequently other sources were needed for construction of new pitches and topdressing of existing pitches. The modified motty test was used to determine the compatibility of two new sources of St John soil, one of which is very similar to the original St John soil. Table 5.4 shows the clay contents and compressive strengths of individual soils and the combination. It is apparent that the difference in clay content does not affect soil strength. Soil spheres split randomly when broken indicating soil compatibility. In comparison, the St John-Redhill and St John-Palmerston North combinations produced soil spheres of lower compressive strength. It appears that the soil with the lowest potential strength value limits the compressive strength recorded for the soil combination. In both combinations, this trend was exacerbated by the motty breaking pattern. The St John-Redhill combination was difficult to mould together at time of making, with the Redhill soil smearing at the interface with the St John half of the motty. Similarly, the St John-Palmerston North spheres were difficult to form. These differences could be explained by variations in soil texture and plasticity indices for the soils within each combination (Table 5.4). By day 5 of drying, cracking had developed around the interface of the St John-Redhill combination. While most breaks were random, this cracking may have contributed to a reduction in motty strength. Breaking of the St John-Palmerston North combinations was not random with most soil spheres splitting in half along the interface between the two soils. The strength value of 30 kg recorded when one motty did break randomly, is evidence that breaking pattern contributes to a loss of compressive strength. On the basis of these results it may be concluded that there could be problems of compatibility between St John and Redhill and St John

TABLE 5.4 Plasticity indices, clay contents, compressive strength values and changes in volume on drying for a selection of individual pitch soils studied and combinations of these soils.

Pitch Soil	Plasticity Index	Clay Content (%)	Compressive Strength (kg)	Change in Volume on Drying (%)
St John	12	42	51 $\pm$ 4	13
St John A	11	36	41 $\pm$ 2	n.d.
St John B	12	43	43 $\pm$ 2	n.d.
Palmerston North	4	28	28 $\pm$ 4	10
Redhill	8	59	34 $\pm$ 1	20
St John A + St John B			44 $\pm$ 2	n.d.
St John + Redhill			27 $\pm$ 4	21
Palmerston North + St John			21 $\pm$ 6	11

n.d. = not determined

and Palmerston North combinations. Practical implications could mean that topdressing an existing St John pitch with Redhill soil could result in development of soil layering unless thorough mixing of both soils is ensured.

Where the properties of one soil provides limitations to the wear characteristics or pace of a pitch, that soil may be modified by mixing with another soil which has desirable properties. Mixing of two soils in varying ratios when dry, and subsequent determination of compressive strength after a standard 5 day A.S.S.B. test, provided useful information. Figure 5.7 shows the relationship between different ratios of St John to Marton soil and motty compressive strength. The 1:2 St John/Marton ratio gave the greatest compressive strength. The strength values were lower either side of this ratio, showing the importance of accurate and uniform soil mixing in the field.

A 1:2 St John-Marton soil mix resulted in a motty compressive strength 15% greater than for the unmixed St John soil, with a corresponding 10% reduction in the Marton soil strength value. Associated with this increased soil strength there should be improved pitch hardness, reduced surface wearing and crumbling at crack edges, and ultimately improved playability. Similarly, Figure 5.8 indicates the relationship between different ratios of St John to Redhill soil and motty compressive strength. Maximum compressive strength was obtained by using either a 1:1 or a 1:2 St John-Redhill mixture. The mixtures could increase the low binding strength of the Redhill soil but decrease that of the St John soil by approximately 20%.

Mixing of soils is not an ultimate solution for improvment of a pitch soil. Mixing must be carried out accurately and uniformly off-site. There is a greater opportunity for error but soil mixing can be of merit where a soil supply requires only slight modification to produce acceptable pitches. While the A.S.S.B. test can be used to provide an indication of which soil ratio may be the most suitable for mixing, it must be remembered that a large number

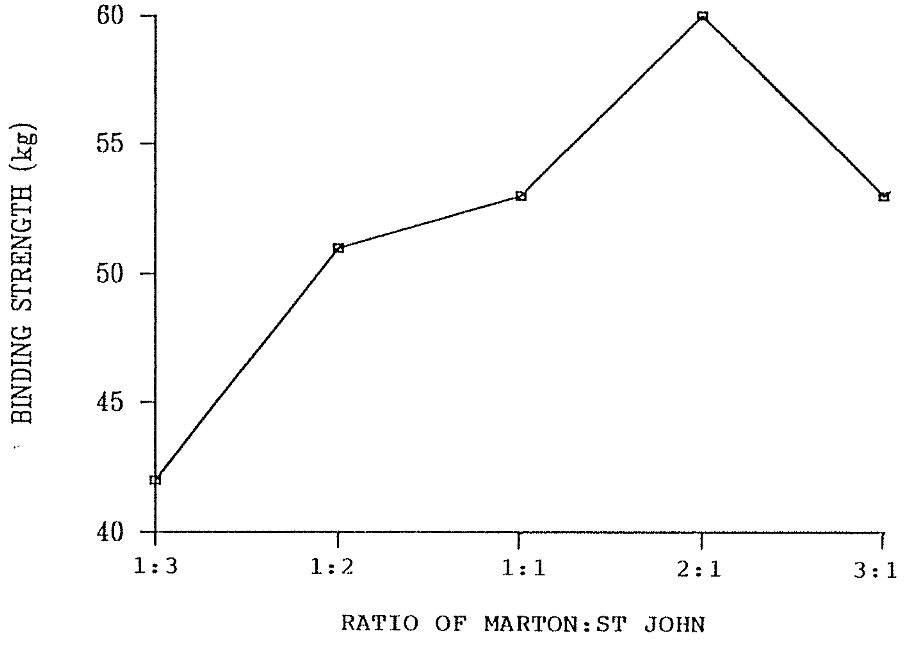


Figure 5.7 Motty binding strength values for varying ratios of Marton/St John soil mixes

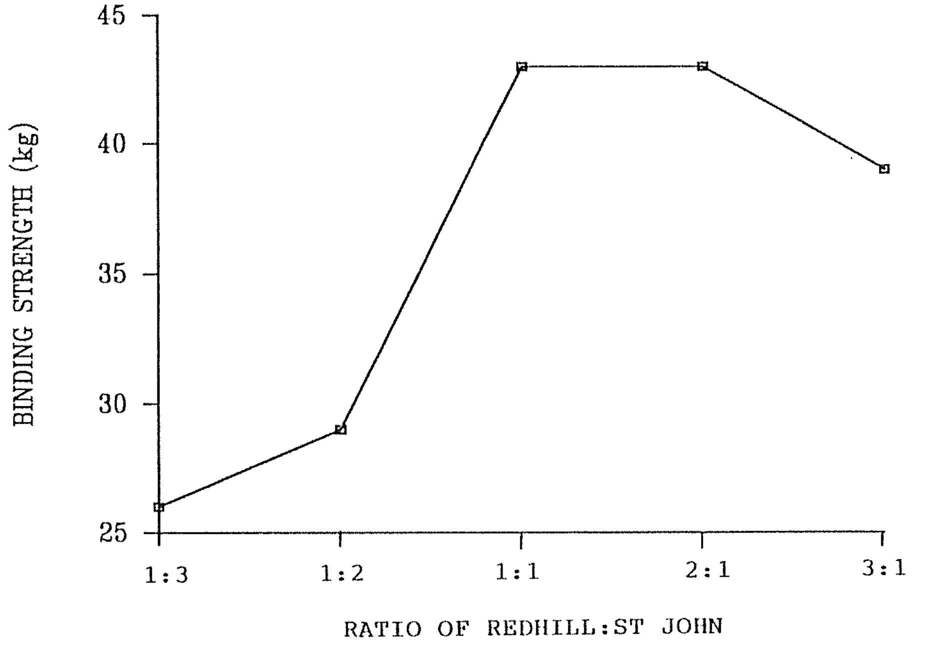


Figure 5.8 Motty binding strength values for varying ratios of St John/Redhill soil mixes

of factors interact to determine suitability and performance of a cricket pitch soil. Full consideration must be given to such factors and soil properties in conjunction with soil strength values before recommendations are made.

Conclusions

1. The modified A.S.S.B. test is a useful technique for determining soil compatibility for use in topdressing cricket pitches.

2. A new source of the St John soil was shown to be compatible with the original and the difference in clay content between the two samples did not appear to detrimentally influence compressive strength.

3. The St John-Palmerston North and St John-Redhill combinations produced spheres of reduced strength. The incompatibility of these soils indicates that layering could develop with topdressing. This incompatibility can probably be explained by the large differences in soil texture and plasticity indices of the two components.

4. Mixing of two soils in varying ratios produces a range of strength values within the limits set by the individual soils of the mix. Each soil mix has an optimum ratio(s) at which binding strength is maximised. This highlights the importance of accurate and uniform mixing in the field.

5. Soil mixing is not the ultimate solution for improved pitch playability but if a soil supply requiring only slight modification is available, this option deserves consideration. The A.S.S.B. test can be used together with a knowledge of other soil properties to define more accurately the optimum ratio of individual soils in a mix.

5.6 Relative Humidity and Motty Drying

The equilibration conditions specified by Stewart and Adams (1969), for soil spheres dried in a controlled chamber are 60-70% relative humidity and 20°C. McAuliffe *et al.* (1987), investigated the effect on compressive strength of different relative humidity levels during motty drying. Three relative humidity levels were used (75%, 90%, 98%). The results indicated that relative humidity has little influence on either soil binding strength or motty end point gravimetric water content (Table 5.5). Differences between each relative humidity level for the soils studied were not significant, which indicates that perhaps the humidity control step of the A.S.S.B. test procedure could be omitted. This is of practical importance for the groundsman testing a soil in the field where access to equipment, and knowledge of scientific procedure is limited. Elimination of this step means that the A.S.S.B. test procedure could be carried out with an acceptable degree of accuracy outside a laboratory if weighing and measuring equipment are available on site.

Conclusions

1. It was found that relative humidity had little influence on either soil binding or motty end point gravimetric water content.

2. Removal of this step from the A.S.S.B. test procedure ensures that binding strength results can be determined with an acceptable level of accuracy by the groundsman using only minimum amounts of scientific equipment.

5.7 Changes in Motty Volume on Drying

The changes in motty volume for the pitch soils at four sizes are shown in Table 5.6. It can be seen that changes in motty volume on drying are relatively constant, irrespective of motty size. This would be expected, given the rate and extent of soil sphere drying during the standard five day drying period (Section 5.4).

TABLE 5.5 The influence of different levels of relative humidity during drying of soil spheres on recorded soil binding strength values and end point gravimetric water contents for two pitch soils.

Pitch Soil	Relative Humidity (%)	Average Compressive Strength (kg)	Average End Point Gravimetric Water Content (%)
Palmerston North[86]	75	63 ± 3	6.2
	90	63 ± 7	5.2
	98	61 ± 9	5.9
Ward	75	68 ± 12	7.6
	90	74 ± 13	7.7
	98	71 ± 12	7.5

TABLE 5.6 Percentage changes in motty volume for the pitch soils studied on Day 5 of the A.S.S.B. test for soil spheres of increasing size.

Pitch Soil	Motty Size			
	1	2	3	4
Palmerston North	11	10	12	10
St John	13	13	14	13
Kakanui	22	22	20	20
Ward	23	22	24	24

1 = 10.1 g; 22.8 mm

2 = 13.5 g; 24.8 mm

3 = 18.2 g; 26.0 mm

4 = 21.4 g; 27.1 mm

More importantly, these results show that differences exist between non swelling and swelling type soils with regard to volume changes on drying. The shrinkage capacity of these soils has been discussed in Section 4.6 and changes in motty volume are consistent with the ranking index established by the shrinkage tests. Changes in motty volume may, therefore, be combined with shrinkage test results to provide additional information about the shrinking and swelling behaviour of pitch soils.

Although the swelling type Ward and Kakanui soils shrank significantly on drying during the motty test, high binding strength values were recorded (Table 5.1). This indicates that development of incipient microcracks on drying of swelling soils may not limit the suitability of the motty test for evaluating these soils as suggested by McIntyre (1983b).

Conclusions

1. Changes in motty volume were found to be constant, irrespective of motty size.

2. Differences between non swelling, limited swelling, and swelling type soils existed with regard to volume change. Changes in motty volume may, therefore, be used in association with shrinkage tests to provide information about potential shrinking and swelling behaviour of pitch soils.

3. Although the swelling type soils did shrink significantly during drying, the high binding strength values recorded suggest that development of incipient microcracks is not a factor limiting the suitability and use of the A.S.S.B. test for evaluation of swelling soils.

CHAPTER 6: PRACTICAL APPLICATION OF SCIENTIFIC PRINCIPLES

6.1 Analytical techniques used to evaluate soil properties and pitch performance in the field

(i) Gravimetric Water Content

Soil water content was determined for three soil depths (0-25 mm; 25-50 mm; 50-75 mm) by a gravimetric sampling method (Appendix 6.1). Two cores were collected at each sampling depth on individual trial plots and combined to provide an average trial plot water content. Treatment replicate results were then combined to give an average gravimetric water content value for each sampling depth and soil-base material study treatment.

During the 1987/88 preparation periods, soil water content was also measured by the backscatter method (Figure 6.1a), using a nuclear moisture-denisty determining device called a nuclear densometer. Correction factors were derived for individual trial plots to improve testing accuracy (McCarthy, 1977).

(ii) Penetration Resistance

A penetrometer (Plate 6.1) was designed and used to quantitatively evaluate the bearing strength or hardness of the pitch soil (Davidson, 1965). The device incorporated a gauge to measure the force required to push a 6 mm diameter needle into the soil surface (0-25 mm) and subsurface (25-50 mm). Penetrometer readings were converted to give values for penetration resistance (kg cm^{-2}). It is noted that these units (kg cm^{-2}) are not S.I. units but have been used for ease of interpretation of results.

A minimum of five readings were taken for each soil testing depth and trial plot. Treatment replicate results were combined to give average surface and subsurface penetration resistances for each soil depth-base material study treatment.

Plate 6.1 Penetrometer used to measure surface and subsurface soil hardness (penetration resistance) of the field trial soils during preparation.

(iii) Bounce Test

The modified bounce test described by Dury (1978), was used to determine ball rebound bounce. The vertical drop height was 3 metres and rebound bounce height was recorded as the height to the top of ball. A minimum of five readings were taken for each trial plot and treatment replicates were combined to give average bounce test results for each soil depth-base material study treatment.

Four piece leather balls were used for testing during the 1986/87 preparations. In an attempt to standardise ball type and eliminate bounce variation caused by ball seam, composite balls were used for testing during the 1987/88 preparations. The composite balls did not bounce as well as the leather balls (approximately 20% reduction in bounce height) but no correlation between ball types was derived. When interpreting the 1987/88 bounce test results this factor was taken into account.

Bounce test values were modified to account for the 15.6% reduction in velocity resulting from the lower drop height (Dury, 1982). Bounce test results reported in this study, therefore, represent the behaviour of a four piece leather ball (1986/87 preparations) and a composite ball (1987/88 preparations) from a drop height of 4.9 metres.

(iv) Soil Bulk Density

During the 1986/87 preparation periods, soil bulk density was measured at three depths (0-25 mm; 25-50 mm; 50-75 mm). A 10 mm diameter corer was used to take samples of known volume, which were weighed, oven dried at 105°C and reweighed. Bulk density (ρb) was calculated as follows:

$$\text{Bulk density } (\rho b) = {}^{M_s}/_{V} \qquad [6.1]$$

where M_s = mass of wet soil minus mass of oven dry soil (g)

V = volume of corer (cm^3)

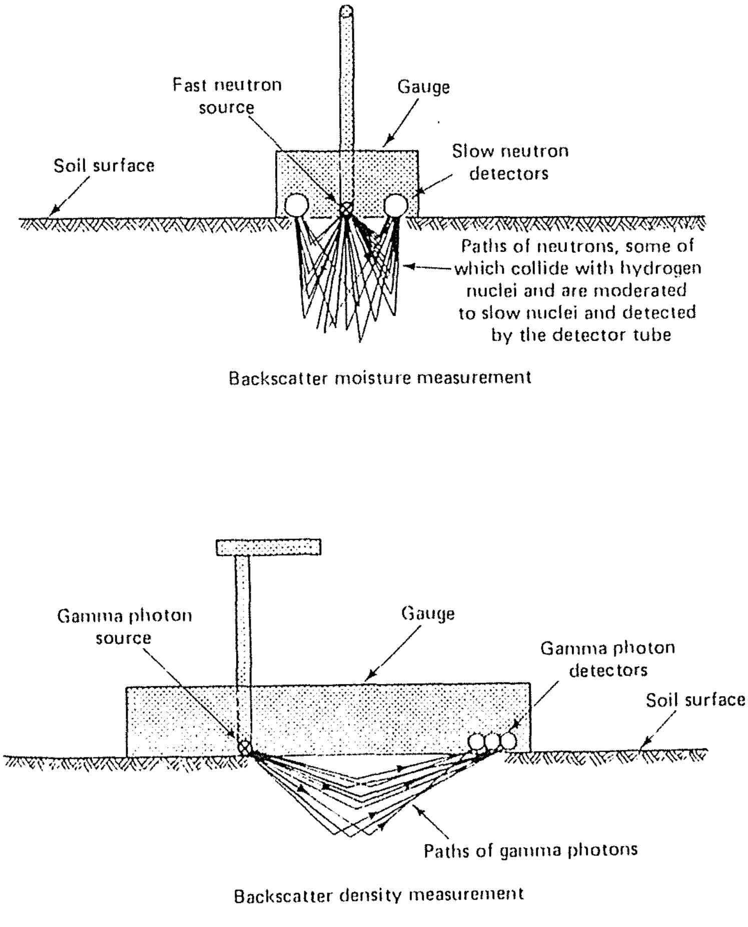


Figure 6.1 Determination of (a) soil moisture content and (b) soil bulk density by the backscatter method using nuclear moisture-density equipment (McCarthy, 1977).

The accuracy of bulk density results determined by this sampling method would be reduced due to the high area ratio of the corer (McIntyre, 1974).

During the 1987/88 preparations, density measurement (Figure 6.1b) was determined non-destructively by a nuclear densometer used for soil moisture content determination. Bulk density results represented an average density from the soil surface to a depth of 100 mm.

(v) Video Monitoring of Ball Trajectory

Ball delivery and rebound bounce, together with the influence of surface friction on pitch pace were assessed by a speed test adapted from Dury (1978). A modified clay pigeon shoot (Plate 6.2) released balls at a velocity of 100 kph and an angle of 18°. Ball trajectory, bounce and speed were recorded by video tape and the results viewed frame by frame on a monitor to provide information on ball bounce and velocity reduction after contact with the pitch surface.

Four piece leather balls were used for the speed test during the second preparation of 1986/87 while composite balls were used during the second preparation 1987/88.

(vii) Infiltration

The soil infiltration rates of the plots were measured by the double-ring infiltrometer method (Bertrand, 1965). The diameters of the inner and outer concentric rings uses were 150 mm and 380 mm, respectively. The use of an outer ring was to provide a buffer effect, whilst the actual infiltration measurement was made by recording the fall of the water level in the central cylinder. Plot surfaces were dry, such that moderate to extensive soil cracking had developed (Appendix 6.16).

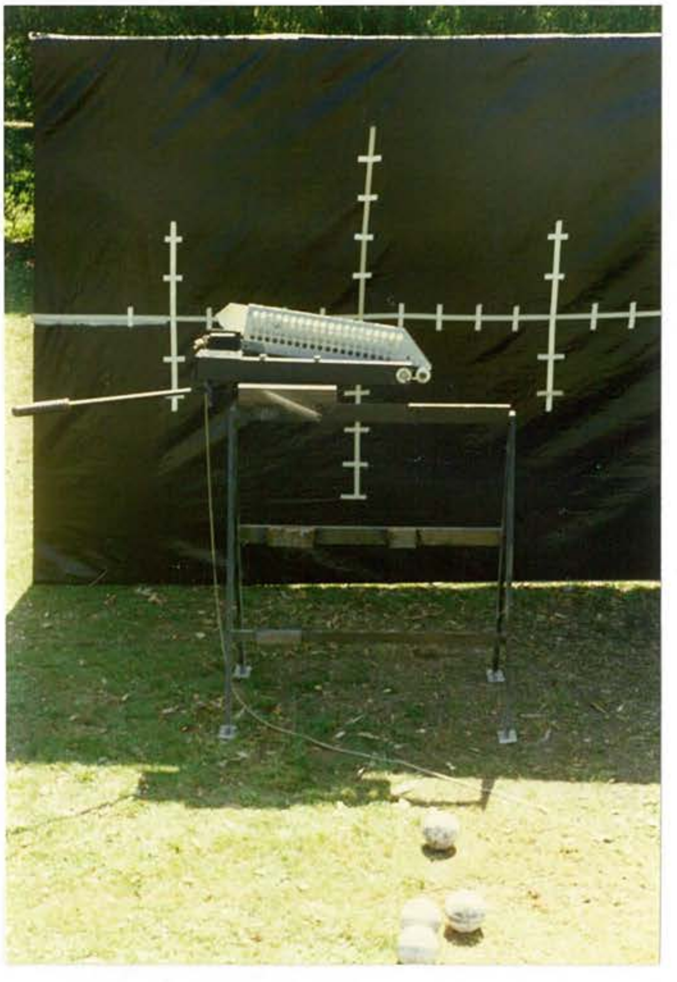


Plate 6.2 The modified clay pigeon shoot used for ball delivery during the speed test assessment of trial plot soils.

6.2 Trial Plot Management During Preparation

(i) Trial Plot Construction

In 1985, a field trial was established at Fitzherbert Park, Palmerston North with the laying down of 32 one metre square trial pitch plots (Plate 6.3). Four soils[1] were used:

1. Ward soil (from Horton Park, Blenheim)
2. Kakanui tar soil (from Centennial Park, Oamaru)
3. Palmerston North soil (from Fitzherbert Park, Palmerston North)
4. St John soil (from Eden Park, Auckland)

Included in the experimental design were two clay soil depth treatments (50 mm and 150 mm), with either existing soil or sand (150 mm) as an underlaying base. Each of the 16 treatments was duplicated. Plots were sown with Barry ryegrass.

(ii) Management Programmes

Management programmes for the 1986/87 and 1987/88 trial plot preparations are outlined in Appendices 6.2-6.5

(iii) Cover System

A 2.5 metre wide cloche system was used to cover the trial plots and provide protection from rain during the preparation periods of 1986/87 and 1987/88 (Plate 6.4).

This cover system was cost effective for research purposes and although performance was generally satisfactory, a number of problems developed with its use. Complete protection was provided during light or moderate rainfall in low wind conditions but the system failed when rain was heavy and continuous, especially when

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[1] The soils are discussed in the introductory summary.

Plate 6.3 Construction of the field trial at Fitzherbert Park, Palmerston North in 1985.

accompanied by wind (second preparation 1987/88). This was mainly due to rainfall exceeding soil infiltration capacity in the buffer strips between trial plot rows. The problem was exacerbated by the level of a number of plots being below the surrounding soil-grass surface as a result of compaction during preparation. During high intensity rain, surface runoff into these trial plots often occurred. High wind (1987/88 preparation periods) also caused collapse of the cloche structures, thereby reducing cover system efficiency.

This type of cover system would not be robust enough to provide the level of protection necessary on a complete pitch but its use has enabled a number of guidelines to be developed for pitch cover design. The system must:

1. Be strong and durable such that it can function effectively during adverse weather conditions.

2. Be portable and offer management flexibility.

3. Have a design capacity ensuring the collection and removal of water away from the pitch area.

4. Provide protection for the area surrounding the immediate pitch as well as the pitch itself.

5. Allow evapotranspiration to continue while the pitch is covered.

These design features could be effectively et by a rigid, wheeled, above-ground structure with a sloping roof line of translucent photosynethically sensitive material, and gutter channels for interception and distribution of roof water runoff to a drainage system. Storage area for a system of this size may be a problem at some venues. This could be overcome by incorporating a collapsibility feature (e.g. telescoping system) into the design framework. While a cover system of this type would be expensive,

Plate 6.4 Cloche system used to provide protection from rain during preparation.

Plate 6.5 Field trial irrigation system.

complete protection from rain during preparation is a basic and essential management requirement. Until first class venues have efficient cover systems, there will always be the possibility of failure due to inclement weather.

(iv) Irrigation

A soak hose-sprinkler system was used to apply water to the trial plots at a rate of approximately 10 mm hr^{-1} (Plate 6.5). The system performed satisfactorily given the financial and logistical constraints of the research programme but management of soil watering was inefficient. Trial plots were watered to saturation at the beginning of each preparation and 5-10 minute irrigation intervals were used during preparation to slow the rate of surface drying.

(v) Rolling

Rolling was carried out during the 1986/87 and 1987/88 preparation periods using roller masses ranging from 500-1500 kg. In the initial stages of the research programme there was a tendency to roll when the soil was outside the optimum soil moisture content range, but compaction efficiency improved with experience and the use of regular soil water content sampling to assist scheduling of rolling operations.

(vi) Mowing

The standard mowing practice used during trial plot preparation maintained the grass cover at a height of 15-20 mm during the early stages of the management programmes. Mowing height was gradually reduced approaching match day and the grass surface was 'scalped' two days before simulated match commencement. The mowing management programme attempted to provide the greatest opportunity for water loss through grass plant transpiration by retaining a high leaf area index and minimising plant stress until the later stages of pitch preparation.

The influence of different grass management practices, namely mowing height and timing of mowing operations, has important implications for soil water loss and pitch performance. Investigation of plant stress and water loss patterns under controlled mowing and management regimes is an important area for future research. The importance of the grass plant is widely recognised but until such information is available, specific recommendations for grass height management and timing of mowing operations cannot be made.

6.3 Weather and the Cricket Pitch

Mean values for a range of climatic inputs influencing pitch management are presented in Table 6.1. It can be seen that only small differences existed between mean daily potential evapotranspiration (PET) rates for the 1986/87 and 1987/88 preparation periods.

Lower mean daily 30 cm soil temperatures were recorded during the November preparation but only small differences existed between December, January, and February months of the 1986/87 and 1987/88 summers. It is unlikely that the November soil temperature value would be limiting turfgrass growth, but there could be important temperature-plant growth interactions occurring at a physiological level which may influence turfgrass development. Such interactions were outside the scope of this study.

Groundsmen state that weather often proves an over-riding factor limiting successful pitch preparation during spring. Playability results recorded for the November preparation of 1987 and December preparation of 1986 indicate that pitches of acceptable standard can be prepared early in the season, particularly if non swelling and limited swelling soils are used (Section 6.4).

The differences in playability observed between spring and summer preparations of 1986/87 may be explained, in part, by the markedly higher mean daily sunshine hours calculated for the second preparation. Light intensity is an important factor for turfgrass

TABLE 6.1 Total rainfall, and mean daily averages for a range of climatic inputs during the trial plot preparation periods of 1986/87 and 1987/88 at Fitzherbert Park, Palmerston North.

Trial Plot Preparation	Date	Total[1] Rainfall (mm)	Mean Daily Values[1] Max Air Temperature (°C)	30 cm Soil Temperature (°C)	Wind Run (km)	Sunshine (hours)	PET
First Preparation	December 1986	18	20.8	17.8	290	5.4	4.8
Second Preparation	January February 1987	62	21.6	19.3	289	7.5	5.1
First Preparation	November 1987	33	19.1	16.6	341	6.8	4.7
Second Preparation	January February March 1988	150	23.2	20.3	327	6.5	4.7

[1] Calculated from meterological data supplied by DSIR, Palmerston North

physiology and growth. In addition, high sunshine hours during the later stages of pitch preparation may assist soil hardening by 'baking' the surface and help brown off the turf cover during the final stages of pitch preparation. Higher sunshine hours, combined with a longer preparation period, probably accounted for the lower soil moisture levels and improved playability recorded during the second preparation of 1986/87 (Section 6.4). Other management factors including grass cover, soil compaction and soil cracking must also be considered along with weather.

The differences in playability found between spring and summer preparations of 1987/88 cannot be explained by weather because wind, sunshine, and evapotranspiration were not significantly different. Improved playability during the second preparation of 1987/88 was probably mainly attributable to the longer preparation time used (due to unseasonal rainfall) (Appendix 6.5). Results of this study indicate that acceptable bounce and pace are more likely to be achieved when the soil is dried extensively and evenly to a depth of 25-75 mm (Section 6.4). Soil drying to depth was more effective during the second preparation of 1987/88. Bearing this in mind, it is likely that early season preparation could be hindered by excessive wetness at depth. This situation might occur if a drainage layer is not present, or subsurface drainage is poor. Subsequent capillarity could create a higher root zone moisture content than would be found later in the season.

Provided a suitable preparation time is allocated to ensure adequate soil drying, and an efficient system of covers is available, pitches of acceptable standard for first class cricket can be produced during spring. A minimum preparation period (3-4) weeks should be allocated. Length of preparation can be fine-tuned by regular gravimetric water content sampling to monitor soil drying rate in response to prevailing weather. A 3-4 week preparation period will give the groundsman an element of flexibility and introduce a safety factor if inclement weather hinders pitch management during preparation. More importantly, the pitch soil will be given the maximum opportunity to dry.

Early season preparation of lower grade pitches is severely restricted by the short preparation time available and possible inclement weather. Covers often provide protection from rain during preparation of first class pitches, but this luxury is rarely afforded lower grade venues, where both financial and labour resources are limiting. Weekly, lower grade pitch use and performance is largely dependent on prevailing weather. Modification of irrigation scheduling may, however, help overcome the characteristic problem of excessive soil moisture. Periodic watering only to relieve grass plant water stress and return the soil moisture content to optimum rolling point, combined with water application at the earliest possible time after the previous match, will assist the development of soil drying and improve pitch playability.

Groundsmen preparing pitches for weekly use could be well advised not to over-water, and they should adapt management programmes to accommodate the reduced drying time available. Such a move will not overcome the vagaries and problems of adverse weather but it could contribute to improved pitch performance.

Moderation of the effects of adverse weather by artificial means, e.g the use of covers, and the time devoted to pitch preparation will also be a function of the intensity of pitch use. Where the number of pitches at a venue is limited and pitches must be used more than once during a season, it may be undesirable to dry the pitch to 'optimal' moisture content for playability. Insufficient time may be available between matches for grass rejuvenation and complete loss of grass cover may be risked if drying is prolonged and pitch use is high.

Conclusions

1. Weather helps to determine the rate of water loss from the soil but it can be moderated e.g by the use of pitch covers.

2. In this study, differences in playability of pitches could not generally be attributed to variations in preparation period or weather, but rather to the extent of soil drying and management factors.

3. Pitches of acceptable standard can be produced in spring, provided a cover system is available and a suitable preparation time (minimum 3-4 weeks) is allocated.

4. The limited preparation time available, and exposure to adverse weather conditions associated with weekly lower grade pitch preparation makes pitch management and soil drying more difficult. Manipulation of irrigation scheduling may, however, help minimise these problems, and provide a greater opportunity for production of pitches with improved playability.

6.4 Pitch playability results from the field trial

(i) Determinants of Bounce

It is widely accepted that playability of pitch soils is largely determined by an interaction between soil water content and hardness (McIntyre, 1983a; Murphy, 1986). The strongest correlations for water content and bounce, and hardness and rebound bounce on match day (as a measure of playability) for each preparation procedure are given in Appendix 6.6.

For the first and second preparations of 1987/88 and second preparation of 1986/87, bounce was most closely related to soil water content at a depth of 25-50 mm. During the second preparation of 1986/87 water content at a depth of 50-75 mm was a more significant determinant of bounce. The results indicate that drying beyond the surface layer and preferably to a depth of 25-75 mm is essential if a pitch is to perform satisfactorily. Such drying can probably best be achieved by the grass plant.

Rebound bounce for the first preparation of 1987/88 and second preparation of 1986/87 was strongly influenced by surface hardness (0-25 mm). Subsurface hardness was a more important bounce determinant on match day of the remaining preparations. It could be concluded therefore, that both surface and subsurface hardness influence rebound bounce.

In general, as subsurface (25-75 mm) soil water content decreased, bounce increased (Appendix 6.7), and the bounce variation was reduced (Appendix 6.8). Bounce increased with increasing soil hardness (Appendix 6.9) but in many cases bounce variation was unchanged or increased with increasing soil hardness (Appendix 6.10).

(ii) Clay Soil Depth

For all soils during each preparation, the 50 mm over sand plots were significantly drier (0-75 mm) on match day than the remaining treatment combinations (Appendices 6.11-6.14). These drying differences developed during the early stages of preparation. While the more extensive drying of shallow soil layers on sand often resulted in significantly higher surface and subsurface hardness for the Palmerston North and St John soils, it did not usually produce significant increases in bounce on match day. Moreover, for the Ward and Kakanui soils, the shallow plots on sand showed greater bounce variation. This could be explained by the excessive cracking which developed on these swelling type soils causing movement of soil blocks on the sand layer. It was concluded that the shallow soil layer-sand base combination was not desirable for swelling type soils.

The rapid drying of the 50 mm plots on sand could be explained by the limited depth of soil available for plant water extraction. Concentration of plant roots in a smaller soil volume occurred because the sand base restricted rooting depth. This probably resulted in more effective transpiration. It was noted that the 50 mm over soil plots did not show the same drying behaviour, indicating that plant roots had penetrated and were extracting water from the soil base.

The use of a shallow (50 mm) layer of non swelling or limited swelling soil on a sand base could have important implications. The more rapid drying of this soil-base combination could be advantageous at lower grade level where a shorter preparation time is available.

For the Palmerston North soil the highest bounce was generally produced on 150 clay soil depths over sand (Appendices 6.11-6.14). This bounce was achieved despite the shallower plots over sand being significantly harder and drier at depth. Perhaps ball energy was transferred horizontally at the sand-soil interface in the shallow plots resulting in loss of ball energy and lower rebound bounce.

In general, bounce increased and bounce variability decreased with 150 mm depths of Ward and Kakanui soils due to the more controlled development of soil cracking and reduced opportunity for movement of soil blocks between cracks.

(iii) Base Material

For all the study soils, sand bases produced significant water content differences for the 50 mm plots. With depths of 150 mm the advantages of a sand base were not as clearly represented. In general, the sand base did not result in significantly lower match day soil water contents at depth for the St John and Palmerston North soils during the preparation periods. Despite the sand and soil base treatments having statistically similar water contents and hardness on match day, values of bounce were higher on the sand bases for the Palmerston North soil.

Sand bases did not produce consistently improved results on the 150 mm Ward and Kakanui plots. In general, for the Ward soil there were no significant differences in water content, hardness, and bounce for the two base treatments. Drying differences were observed on the Kakanui soil. The 150 mm plots over sand were generally significantly drier than the soil base treatments during the first and second preparations of 1986/87 but this did not usually result in significant hardness and rebound bounce differences.

(iv) Differences Between Soils

The Palmerston North soil performed better than the St John, Ward, and Kakanui soils when bounce was measured. On match day of the first and second preparations of 1987/88 and second preparation of 1986, rebound bounce was significantly higher than for the Ward and Kakanui soils (Appendices 6.13-6.14). This can be explained by the significantly lower levels of soil moisture and greater subsurface (25-50 mm) hardness (Appendices 6.13-6.14). Further, the non-expansive nature of the Palmerston North soil meant that rebound bounce and bounce variation were not detrimentally affected by soil cracking.

The St John soil produced consistently higher absolute bounce test values than the Ward and Kakanui soils but lower rebound bounce than the Palmerston North soil. The differences between the St John, Ward, and Kakanui soils were, however, only statistically different for the second preparation of 1986/87 due to the variation associated with the bounce test measurements (Appendix 6.12). The St John soil was significantly drier than the Ward and Kakanui soils at depth on match day of each preparation which highlights the more favourable water retention characteristics of soils with lower clay contents and minor amounts of smectite clay minerals.

The Palmerston North soil produced higher absolute values of bounce than the St John soil. During the first and second preparations of 1986/87 and 1987/88, the differences in bounce could be explained by the higher subsurface water content and corresponding lower subsurface hardness of the St John soil.

When absolute bounce test values were used to provide an estimate of pitch pace, the pitch soil differences were further highlighted. During the second preparations of 1986/87 and 1987/88 the Palmerston North soil could be classified as providing an easy paced to fast pitch. The St John soil was easy paced to fast on match day of the second preparation of 1986/87 but only easy paced for the second preparation of 1987/88. The difference could probably be explained, in part, by the different ball used (Section 6.1) and by the lower subsurface hardness recorded for the St John soil. The Ward and Kakanui soils were easy paced to fast for the second preparation of 1986/87. This shows that the swelling type soils can produce pitches of acceptable pace. Soil water contents for the Ward and Kakanui soils were significantly higher than those measured in the Palmerston North and St John soils on match day of the second preparation of 1986/87 (Appendix 6.12). As there were no significant differences in hardness between soils, it was concluded that soil water content was the factor limiting further bounce improvement on the Ward and Kakanui soils. This illustrates the problems associated with drying swelling type soils adequately to depth. The Ward and Kakanui soils did not perform favourably on match day of the remaining preparation periods. Pitch pace was slow to very slow due to high subsurface water contents. This reflects the unsuitability of short preparation periods to achieve sufficient soil drying (first preparations 1986/87, 1987/88) and the difficulties of managing swelling soils over an extended preparation period (second preparation 1987/88). The short management period of the first preparation also detrimentally affected soil drying of the Palmerston North and St John soils, resulting in only medium to easy paced pitches being produced. It is essential, therefore, that sufficient time be allowed during preparation to ensure extensive soil drying; for swelling type soils it is critical.

6.5 Evaluation of soil monitoring techniques and their potential as management tools for the groundsman

(i) Soil Water Content Determination

Soil water content is an important parameter determining pitch management and playability. It follows, therefore, that soil water content monitoring during preparation is a powerful management tool available to the groundsman. A knowledge of changes in water content over time enables the groundsman to monitor the progress of soil drying during preparation and fine-tune the management programme accordingly. Further, the groundsman, through a knowledge of soil water content at depth, can predict pitch playability. The guesswork is taken out of pitch preparation and the art becomes a science.

Opposition to gravimetric sampling for water content determination arises because core samples must be taken from the pitch. If samples are collected from the stump region and the core holes are refilled with soil this problem can be overcome.

The frequency of sampling during the early stages of pitch preparation is dependent on the the information required by the groundsman when scheduling irrigation and rolling programmes. During the later stages of preparation, water content determination can be used to assess potential playability and sampling frequency can be reduced. The need for gravimetric sampling can be further reduced once an information base has been established and a soil management programme developed.

The procedure for gravimetric water content sampling is given in Appendix 6.1. It may be possible to reduce the 24 hour waiting time for oven drying by drying soil samples using a microwave technique (Miller *et al.*, 1974; Hanking and Sawhney, 1978; Gee and Dodson, 1981). This would ensure results are available within 30 minutes of sampling and would increase flexibility and accuracy of management decisions.

The use of indirect non destructive methods for measuring soil water content have possible application to the cricket pitch. A nuclear densometer was used on the trial plots to measure soil moisture (0-100 mm) during the 1987/88 preparation periods. When calibrated, the results compared favourably with water content determined by gravimetric sampling. While the nuclear densometer does not allow differentiation of water content with depth, it could be used in conjunction with gravimetric water content determination to reduce the frequency of destructive sampling. In addition, it is quick and easy to use once calibrated.

(ii) Penetration Resistance

The penetrometer is a useful tool for the groundsman to monitor soil drying and development of hardness during preparation. The device is portable, inexpensive, easy to use, and a large number of measurements can be collected quickly. By calibrating penetration resistance with soil water content, the penetrometer can also be used to fine-tune scheduling of rolling operations and monitor playability during preparation.

(iii) Bounce Test

Although the bounce test has limitations, it is a simple and inexpensive method for evaluating pitch playability.

Two major problems restrict the use of this test. Firstly the bounce test is cumbersome to operate (even at the modified 3 metre drop height) and requires two people to collect data. Consequently, its use has met opposition from groundsmen. Secondly, the type of ball used in the bounce test has a significant influence on the rebound bounce recorded. Dury (1978), found that the ball used for a match (or bounce test experiment) has a major bearing on the level of bounce recorded (up to 10% variation). To examine this point, a comparative trial was conducted using the 'standard' 4 piece Kookaburra ball and a 2 piece leather ball. From Table 6.2 it can be seen that significant differences in rebound height were measured for the 2 piece and 4 piece balls. Typically, bounce was approximately 20 cm higher with the 2 piece ball. This illustrates the importance of specifying the type of ball when testing bounce and comparing playability results from different venues and on different soils.

The time of day also influenced rebound bounce values. Results in Table 6.3 show that bounce measured on match day of the second preparation of 1987/88 was higher in the afternoon than the morning. In general, differences were not statistically significant but absolute values were commonly 10-15% higher. This is consistent

Table 6.2 **A comparison of rebound bounce (cm) recorded for two different balls on the main pitch and trial plots at Fitzherbert Park during the 1986/87 preparation period.**

Date	Venue	4 piece ball	2 piece ball
19/1/87	Main Pitch Fitzherbert Park	61 ± 5	85 ± 9
20/1/87	Main Pitch Fitzherbert Park	80 ± 5	100 ± 8
9/2/87	Main Pitch Fitzherbert Park	75 ± 12	99 ± 10
12/2/87	Trial Plots Fitzherbert Park	44[1]	64[1]

[1]Mean value for all plot treatments

Table 6.3 **A comparison of mean rebound bounce heights recorded on the trial pitch soils for morning and afternoon sampling on match day of the second preparation of 1987/88.**

		Rebound Bounce (cm)	
Soil	Depth-Base Combination	Morning	Afternoon
Palmerston North	50 mm sand	58 ± 9	69 ± 10
	150 mm sand	67 ± 8	75 ± 9
Ward	50 mm sand	33 ± 8	42 ± 10
	150 mm soil	39 ± 11	48 ± 8
St John	50 mm sand	47 ± 9	52 ± 4
	150 mm sand	50 ± 56	53 ± 7
Kakanui	50 mm sand	30 ± 7	39 ± 9
	150 mm soil	25 ± 12	45 ± 4

with the development of pitch pace during a match and may be explained by drying of the pitch soil during the day and changes in ball behaviour due to increasing air temperature.

An alternative to the bounce test is the objective assessment of pitch playability by the Clegg impact hammer. Lush (1985), stated that the results generated by this device correlated well with measured rebound bounce. Portability, and ease and speed of operation of the impact hammer are desirable features. A future area of research in New Zealand could involve evaluation of the impact hammer on New Zealand pitch soils and the development of a pace rating scale comparable with the bounce test.

(iv) Speed Test (Video Analysis of Ball Trajectory)

From Appendix 6.15 it can be seen that velocity off the pitch soils was relatively constant across all plots, with a reduction in speed after contact ranging from 20-30%. Rebound bounce height with the ball delivery machine showed the Palmerston North soil to have the highest bounce followed by the St John soil, with the two swelling clay soils having least bounce. This was similar to the trend measured for the bounce test but bounce sensitivity was reduced. The speed test did reveal considerable variability in bounce height on some plots e.g. the 50 mm Kakanui and Ward plots.

Comparison of 1986/87 and 1987/88 results is limited by the difference in balls used at each testing date (Section 6.1) but it can be seen that pitch pace was reduced across all soils on match day of the second preparation of 1987/88. This was despite similar bounce height at 3 metres and surface preparation by rolling during the later stages of the second preparation of 1986/87 (Appendix 6.15). It could be concluded that pitch pace during the second preparation of 1986/87 was superior to that for the second preparation 1987/88, a finding supported by the bounce test results. The influence of surface preparation on rebound bounce, bounce variability and pitch pace is an area for future research.

The speed test requires specialised equiment and its use is, therefore, restricted to research. Furthermore, the method is labour intensive and does not provide information additional to other tests, so it probably has limited value to the groundsman.

Conclusions

1. Soil water content monitoring is the most powerful management tool available to the groundsman during pitch preparation.

2. Gravimetric water content sampling procedure is quick, simple and requires minimum amounts of scientific equipment.

3. Sampling (destructive) frequency can be reduced by using a nuclear moisture-density measuring device to monitor soil water content. A nuclear densometer is portable, quick and easy to use and when calibrated produces accurate results.

4. The penetrometer is a highly portable, inexpensive and simple instrument which can be used in conjunction with water content determination to help the groundsman with timing of management operations.

5. The bounce test is limited by its cumbersome design and the influence of ball type on rebound bounce. A more suitable method for assessment of pitch playability could be the Clegg impact hammer. Future research should look to calibrating this device for New Zealand pitch soils.

6. The speed test requires specialized equipment, therefore, its use is restricted to research. The method is labour intensive and does not provide information additional to other tests, so it probably has limited value to the groundsman.

6.6 Soil bulk density and compaction in the field

(i) 1986/87 Preparations

During the 1986/87 preparation periods, bulk density sampling was undertaken on each trial plot (McAuliffe *et al.*, 1987). There were no significant differences between the four soil depth-base material treatment combinations for each soil so only mean values are presented in Table 6.4.

The bulk density results indicate that significantly better compaction, therefore more efficient rolling, of the Ward and Kakanui soils was achieved during the second preparation period. This was probably due to differences in the rate of surface evaporation, whereby a slower surface drying rate was maintained during the second preparation.

The improved soil bulk density measured during the second preparation may help explain the higher bounce recorded on the Ward and Kakanui soils at this time (Section 6.4).

The Palmerston North and St John soils were uniformly compacted to 75 mm depth during the second preparation. In comparison, the Ward and Kakanui soils appeared to be inadequately compacted at depths below 50 mm (Table 6.4). This may also have contributed to the lower bounce recorded for the Ward and Kakanui soils (Appendix 6.11) and highlights the importance of adequate subsurface compaction, together with low levels of soil moisture to produce optimum playability.

Measurement of bulk density following physical treatment by sub-aeration after the first preparation showed that this technique significantly reduced soil compaction (Table 6.4). It could be expected that this compaction relief would, in turn, improve soil aeration, water movement, and potential grass root development through the soil.

From Table 6.4 it can be seen that levels of compaction attained during the second preparation were comparable with those of the first preparation. This indicates that physical treatment did not detrimentally affect the level of soil compaction reached during the subsequent preparation period, and may provide a case for physical renovation of pitches during the season if compaction is limiting grass growth or soil layering has developed. It must be noted, however, that the success of compaction relief is largely dependent on the soil moisture content at time of physical treatment (Section 6.10).

(ii) 1987/88 Preparation

During the 1987/88 summer, soil compaction was determined non-destructively using a Nuclear Densometer (Section 6.1). This method of density evaluation overcame the problem associated with core removal from the pitch, and may have produced more accurate bulk density results. It did not, however, allow differential changes in soil compaction with depth to be measured, the value recorded representing average bulk density from the surface to a depth of 100 mm.

As was found during the 1986/87 sampling periods, no significant differences in bulk density occurred between the four soil depth-base material treatment combinations for each soil studied. Results given in Table 6.4 are mean values for each soil type. The results show that over a 38 day interval (during which there was no rolling), subsequent to the first preparation and prior to the second, there was no significant change in bulk density for each of the trial soils. This may have implications for the development of pre-season and early season rolling programmes. If an acceptable base level of soil compaction can be achieved by early season rolling, then the amount of rolling needed for soil compaction during match preparation could be markedly reduced, especially if rolling operations are timed for greatest efficiency (Section 4.5).

TABLE 6.4 Mean values of bulk density recorded on the trial plots during the 1986/87 and 1987/88 preparation periods and the main pitch at Fitzherbert Park, during the 1987/88 season.

	First Preparation December 1986	Pre-second Prepration			Second Preparation February 1987	
Pitch soil	(0-50 mm)	(0-50 mm)	(50-100 mm)	(0-25 mm)	(25-50 mm)	(50-75 mm)
Palmerston North	1.52 ± 0.06	1.39 ± 0.08	1.42 ± 0.08	1.52 ± 0.09	1.54 ± 0.07	1.54 ± 0.04
Ward	1.35 ± 0.02	1.28 ± 0.04	1.27 ± 0.09	1.48 ± 0.08	1.48 ± 0.03	1.40 ± 0.03
St John	1.46 ± 0.05	1.32 ± 0.05	1.30 ± 0.03	1.49 ± 0.05	1.50 ± 0.05	1.45 ± 0.09
Kakanui	1.47 ± 0.05	1.36 ± 0.08	1.36 ± 0.05	1.59 ± 0.06	1.50 ± 0.07	1.44 ± 0.06

	Pre-Second Preparation 13/12/87 (0-100 mm)	Second Preparation 20/1/88 (Day 1) (0-100 mm)	Second Preparation 2/2/88 (Day 12) (10-100 mm)	Second Preparation 4/3/88 (Day 42) (0-100 mm)	Fitzherbert Park[1] 2/2/88 (0-100 mm)
Palmerston North	1.52 ± 0.05	1.49 ± 0.04	1.59 ± 0.04	1.59 ± 0.05	1.31 ± 0.02
Ward	1.35 ± 0.03	1.32 ± 0.03	1.42 ± 0.04	1.44 ± 0.01	
St John	1.42 ± 0.04	1.40 ± 0.05	1.50 ± 0.05	1.53 ± 0.04	
Kakanui	1.45 ± 0.07	1.40 ± 0.04	1.52 ± 0.04	1.53 ± 0.04	

[1] Main Pitch

Significant differences were measured in the compaction level for each soil during the early stages of the second preparation period. This was probably due to the rolling undertaken between days 3 and 12 (Appendix 6.5). Comparison of bulk density values on Day 12 and Day 44 of the second preparation (Table 6.4) indicates that the level of compaction was maintained, but not increased despite the extended preparation period (including additional rolling) forced by unseasonal rain (Section 6.3). Match day bulk densities (Day 44) were similar to the maximum bulk density recorded for each soil by the ordinary Proctor compaction test (Table 4.5). As the compaction force used in the Proctor test was similar to that applied during rolling (Appendix 4.7), a further increase in soil bulk density could only be achieved by heavier rolling equipment and more efficient rolling programmes.

Differences in bounce and penetration resistance between days 12 and 44 of the second preparation are most likely attributable to variations in measured subsurface soil water content (Section 6.4). Therefore, once an acceptable base level of soil compaction is attained, drying of the pitch soil to depth becomes the major factor determining playability. This is consistent with the findings of Murphy (1986).

Murphy (1987), argued that high bulk density (soil compaction) at the begining of match preparation is advantageous because less water is held in the soil due to reduced porosity, therefore, less water would need to be removed by match day. The influence of compaction on overall water content of a soil at equilibrium, however, is not simplistic and can be difficult to predict. Compaction of a soil of low bulk density, results in the removal of air and the pushing together of soil particles. This causes elimination or reduction in size of macropores ($>$ 0.06 mm size) upon which drainage and aeration are dependent. Micropores ($<$ 0.06 mm size) hold plant available water so if they are reduced in size and number due to compaction it could be expected that the soil would become more droughty and require more frequent irrigation. An increase in the number of micropores could have serious implications for pitch soil drying because the water present in the micropores is often held so tightly that it is unavailable to grass plants. Possibly then, a more compacted soil with a higher proportion of micropores contains more water beyond permanent wilting point. Further, plant growth restrictions due to soil compaction could lead to less effective soil drying.

The area of soil water-plant interaction in response to varying levels of soil compaction is an important one, and requires additional research before recommendations can be made. It does, however, highlight the difficulties of obtaining a balanced compromise between acceptable levels of soil compaction for improved playability, and the development of an extensive grass cover, upon which pitch management is dependent.

(iii) 1986/87 vs 1987/88 Preparation

Comparison of the bulk density results for the second preparations of 1986/87 and 1987/88 shows that the levels of compaction for each soil were similar (Table 6.4). It may be concluded, therefore, that differences in playability observed (Section 6.4) reflect differences in other management factors such as soil water content and soil cracking-cover interactions rather than compaction.

(iv) Trial Plots vs Fitzherbert Park Pitch

Soil bulk density of the trial plots during the second preparation of 1987/88 was significantly higher than that recorded at Fitzherbert Park during pitch preparation for the Central Districts *vs* Northern Districts fixture (Table 6.4). Differences in measured bulk density were probably due to the more intensive preparation of the trial plots during the 1987/88 season. The results indicate that soil compaction, hardness, bounce, and pace may be increased on the Fitzherbert Park pitch by a more intensive rolling programme. Match preparation included 27 hours of rolling (pers. comm. K. Timms) so this compaction improvement could probably be most effectively achieved by increasing the amount of early season rolling.

(v) Surface Preparation

During the final stages of pitch preparation when low levels of soil moisture have been reached, the use of rolling for surface preparation becomes an important management tool. Surface preparation by rolling is used to produce a smooth, hard surface to increase the pace of the ball off the pitch. Rolling for this purpose is considered best undertaken during the hottest part of the day (pers. comm. K. Timms). The pitch is sprinkled lightly with water and rolling commenced at a faster speed than normal. The surface is rewetted upon drying, and the procedure repeated during a 2-3 day period prior to match commencement. On match day, the grass cover should be browned off and incorporated into the pitch surface to produce a glazed hard finish (pers. comm. K. Timms).

As bulk density could not be measured differentially to depth (Section 6.1), it was not possible to quantify the influence of this surface preparation on surface layer compaction. Results of surface penetration resistance showed that surface hardness increased during the second preparation of 1987/88, and this can probably be attributed, in part, to the surface preparation, along with the lower measured soil moisture content. The influence of surface preparation on pitch pace is discussed in Section 6.5.

Conclusions

1. Soil bulk density did not change significantly over time, even in swelling type soils. Pre-season and early season rolling may, therefore, be used to establish a base level of soil compaction.

2. If an acceptable base level of soil compaction can be achieved by early season rolling, then the amount of rolling needed for soil compaction during match preparation could be reduced.

3. The base level of soil compaction developed is a compromise between achieving acceptable levels of bulk density to depth for improved playability, and the survival of the grass plant in an unfavourable rooting environment.

4. Comparison of Proctor compaction density values with measured soil bulk density during preparation allows compaction development to be monitored and the rolling management programme to be fine-tuned (e.g. roller mass, duration of rolling).

5. The nuclear densometer is a useful tool for measuring bulk density non-destructively but its use is limited by only providing average density values from the surface to a depth of 100mm.

6. Physical treatment of compacted soils by sub-aeration reduced soil bulk density. Pitch preparation began within 6 weeks of renovation without detriment to soil or playability.

7. Differences in pitch playability are most likely a result of variations in measured soil water content once base levels of compaction have been achieved.

8. Rolling for surface preparation is an important aspect of pitch management to produce a harder, smoother surface for improved bounce and pace.

6.7 Pitch soil cracking and grass cover

During the 1986/87 and 1987/88 preparation periods the extent of soil cracking on drying and changes in grass cover over time were assessed, and comparisons were made between soils using ranking indices shown in Appendices 6.16-6.18.

From Appendices 6.16-6.18 it can be seen that the four soils under study varied in their susceptibility to cracking. Cracking is largely determined by the types of clay minerals present in the pitch soil (Section 2.1).

Results on Day 5 of the first preparation (1986/87) show the extent of cracking before watering (Appendix 6.16). The Palmerston North soil exhibited only minimal or minor cracking, with the hairline cracks present being characteristic of a non swelling soil (Plate 6.6). The limited swelling St John soil showed minor to moderate cracking, and the 1-2 mm wide cracks (Plate 4.2) that developed reflect the minor contribution of smectite minerals to the clay mineral assemblage of this soil (Section 2.1).

The swelling type Ward and Kakanui soils cracked significantly, as predicted by the shrinkage tests (Section 4.7). The greater development of soil cracking shown by the Ward soil during the first preparation period of 1986/87 (Appendix 6.16) can be explained by the poorer grass cover on these soil plots. Furthermore, the more extensive development of cracking by the Ward soil when compared to the Kakanui soil may be a function of the higher clay content of this soil (Section 4.1).

After watering to saturation, cracking was monitored at regular intervals to match day (Appendix 6.16). The extent of cracking exhibited for the St John and Palmerston North soils was similar to that measured on Day 5, but the Ward and Kakanui soils showed increased cracking behaviour. Crack widths were variable, ranging from 5-10 mm. Cracking patterns on the 50 mm soil over sand plots were excessive for both soils (Plate 6.7). In the case of the Ward soil, this resulted in instability and movement of soil blocks between cracks. This instability may have been due to shallow soil drying during the early stages of preparation, accompanied by rolling when the surface was too dry, causing a cleavage plane at the moist soil-dry soil interface and breakage of the few plant roots present.

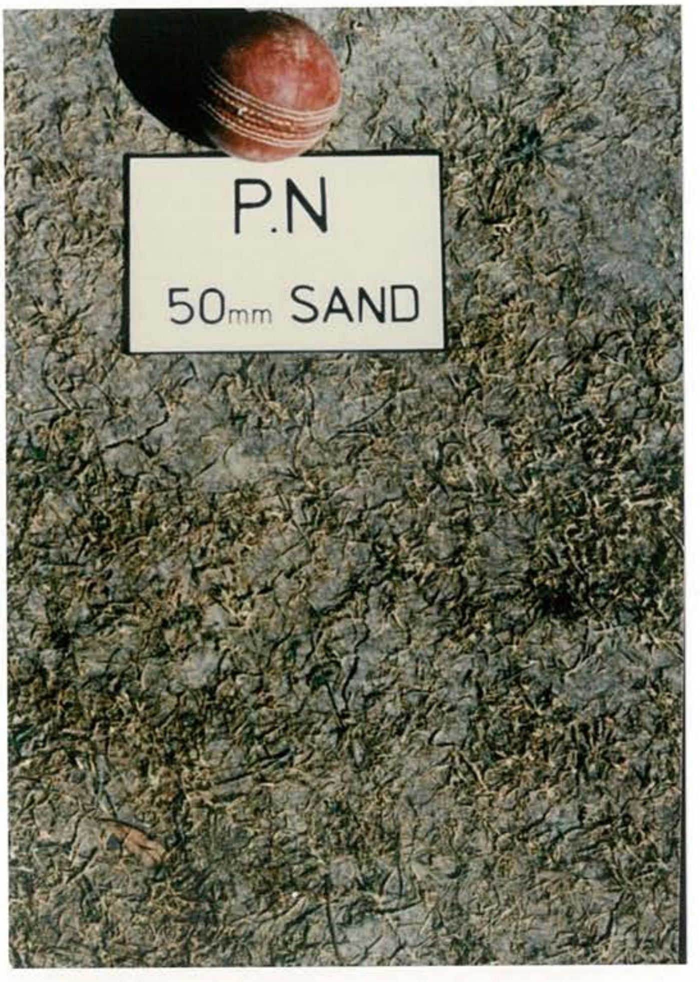


Plate 6.6 Minimal to minor (1-2 mm) cracking characteristic of the non swelling Palmerston North soil.

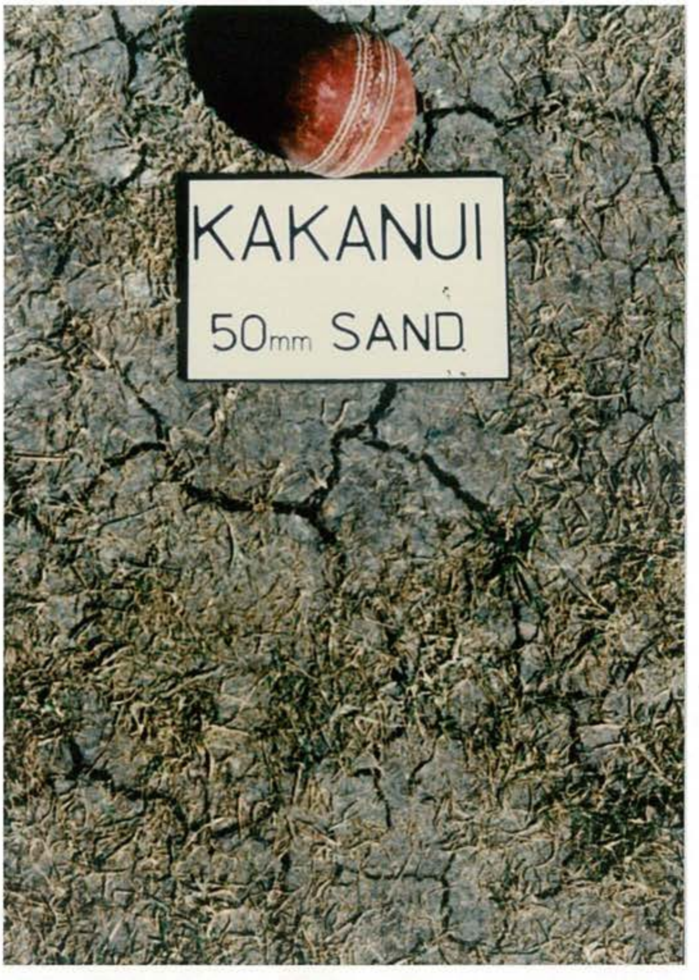


Plate 6.7 Excessive cracking developed on the 50 mm over sand plots for the Kakanui soil during the first preparation of 1986/87.

The important role of the grass plant in drying swelling soils evenly to depth has been discussed in Section 1.3 (iv). The poor plant cover established on many of the trial plots (Appendices 6.16-6.18) no doubt reduced the effectiveness of this drying mechanism.

Bounce test results and speed test analysis of the soils showed that the extent of cracking on the shallow swelling type clay soil plots over a sand base influenced playability. It can, therefore, be concluded that greater depths of the clay soil layer are required for swelling type soils, especially when grass cover is poor.

The poor grass cover on the Palmerston North plots (Appendices 6.16-6.18) may be a reflection of the unfavourable physical conditions provided by compacted non swelling soils. In comparison, the swelling type Ward and Kakanui soils with self-mulching tendencies had a natural mechanism for compaction relief, with root penetration and grass growth assisted by soil cracking. This highlights the need for regular physical treatment of non swelling soils if a deeply-rooted, uniform grass cover is to be maintained from one season to the next.

Between the first and second preparation (1986/87) periods the plots were renovated (Section 6.10). Appendix 6.17 shows that the grass cover present during the second preparation of 1986/87 improved as a result of this physical treatment. The improved grass cover may have contributed to the more effective drying to depth achieved at this time (Appendix 6.12).

Approaching match day, crack widths for the St John soil were 2-4 mm, while those for the Ward and Kakanui soils were commonly 5-8 mm. The more controlled cracking developed by the swelling type soils, as shown on Day 19 of the second preparation, probably also reflects the retarding of surface evaporation through light frequent waterings whenever the soil surface started to appear dry (Appendix 6.17).

On Day 27 of the second preparation, soil drying reached levels causing extensive to excessive cracking of the swelling type soils. Associated with this cracking was instability of soil blocks between cracks and crumbling of crack edges. Fracturing and crumbling observed near crack edges for swelling soils indicates that drying beyond a certain soil moisture content reduced the inherent soil strength. The practical implication may be the development of an increasingly uneven surface and possibly a pitch which promotes excessive spin and variable bounce as the match progresses.

Cracking and grass cover was not closely monitored during the first preparation period of 1987/88. It was observed, however, that an acceptable grass cover was present on the majority of trial plots. Few problems were encountered with excessive soil cracking; probably due directly to the improved grass cover, and the limited soil drying achieved (Appendix 6.13).

The poor grass cover for the second preparation of 1987/88 (Appendix 6.18) probably resulted from a combination of the adverse effects of compaction and plant stress during the first preparation and close mowing in December 1987.

The cracking behaviour for the pitch soils during the second preparation of 1987/88 was similar to that observed during the second preparation of 1986/87. Due to inclement weather (Section 6.3), management was difficult but this provided a test of soil behaviour over a prolonged preparation period featuring a number of wetting and drying cycles. Playability results (Section 6.4) showed that the soils could be prepared under adverse weather conditions but in this instance time was not a constraint. The extent of cracking varied according to soil moisture levels, and the development of cracking was consistent with the potential cracking capacity of each soil, irrespective of the wetting and drying cycles and length of preparation time. It was noted, however, that preparation of the swelling type soils was more difficult under such conditions and optimum playability results were not achieved (Appendix 6.14). Wetting and drying cycles, causing a corresponding manifestation of repeated shrinkage and swelling behaviour in the field, could have resulted in an increased susceptibility to soil instability with swelling type soils. In turn there was an increased opportunity for development of self-mulching tendencies and crumbling of crack edges. This instability was counteracted by the action of the roller when used to 'shine' the pitch surface (Section 6.6), but would probably become more important as the match progressed.

Conclusions

1. Pitch soils have different field cracking potentials determined by the type of clay minerals present in the soil.

2. There was a strong relationship between soil cracking and grass cover. A uniform grass cover can moderate the development of soil cracking by 'knitting' soil blocks together. Furthermore, a dense sward may slow the rate of surface drying, thereby promoting water removal evenly from depth, and assisting the production of regular cracking patterns.

3. Extensive cracking influenced playability by causing bounce variation particularly when crack edges were unstable or cracking was shallow. This bounce variation was strongly expressed with shallow layers of swelling soils on sand bases.

4. Soils which cracked moderately (cracks < 5 mm wide at match day) were easier to manage and produced superior playability. For these soils, establishment of grass cover was not as critical to produce a pitch of acceptable standard.

5. Non swelling and limited swelling soils require off season renovation to overcome the detrimental effects of soil compaction.

6.8 Comparison of Palmerston North and St John trial plots with pitches prepared for first class cricket during 1987/88 season.

Subjective assessment of pitch performance (match reports) was combined with a description of soil water content, hardness, and bounce for a selection of first class matches on St John and Palmerston North pitches. The results, summarised in Table 6.5 allow data collected from the trial plots in Palmerston North to be compared with results obtained for similar in situ soils in match situations.

The St John pitches produced at Eden Park No.2 and Cornwall Park were, in general, medium-paced with medium but consistent bounce. There was a tendency, however, to maintain the pitch soil moisture contents at higher than desirable levels for optimum playability. Examples of the failure to remove sufficient water from the soil at depth (25-75 mm) are given in Table 6.5 for the Auckland *vs* Northern Districts, Auckland *vs* Wellington (31.1.88), India Youth *vs* New Zealand Youth and New Zealand *vs* England matches. Further, the pitches with high surface (0-25 mm) water contents were characterised by excessive ball movement off the pitch during the early stages of the 1-day matches on the 3/1/88 and the 19/3/88 (Match Report). The high surface moisture contents recorded may also account for the slow to medium paced pitches produced and the decreased soil hardness measured at that time (Table 6.5).

The failure to dry the St John pitches to optimum levels of soil moisture may reflect the reluctance of groundstaff to allow development of soil cracking, coupled with possible weather constraints. This is of particular relevance to Eden Park, where soil drying and cracking problems have been encountered with the swelling Port Albert soil in the past. The St John soil is a limited swelling type characterised by 2-4 mm cracks when thoroughly dry which do not influence playability (Section 6.7). If the pitch is prepared correctly and a good grass cover is established prior to preparation, there should be no movement of blocks between cracks and crack edges should not crumble (Plate 6.8).

TABLE 6.5 An assessment of playability for the St John and Palmerston North soils on in situ pitches prepared for first class cricket during the 1987/88 season.

Date	Venue	Fixture	Day	Average Water Content (%) 0-25 mm	25-50mm	50-75 mm	Average Penetration Resistance (kg cm^{-2}) Surface	Subsurface	Bounce (cm)
20/11/87	Fitzherbert Park Palmerston North	Manawatu *vs* Hawkes Bay	1	22.2	19.8	20.1	144	116	50
1/12/87	Cornwall Park Auckland	Auckland *vs* Northern Districts	1	22.2	25.8	26.1	-	-	
			2	20.5	26.6	26.9	-	-	71
11/12/87	Eden Park No. 2 Auckland	Auckland *vs* Northland	1	23.0	20.6	27.3			
22/12/87	Eden Park No. 2 Auckland	Auckland *vs* Canterbury	1	17.0	17.7	19.9	230	144	54
3/ 1/88	Eden Park No. 2 Auckland	Auckland *vs* Wellington	1	23.4	21.5	22.0	170	-	49
13-15/1/88	Eden Park No. 2 Auckland	Auckland *vs* Wellington	1	19.1	19.3	22.3	221	-	
			3	15.0	17.0	19.7	-	-	-
6-8/2/88	Fitzherbert Park Palmerston North	Central Districts *vs* Northern Districts	3	16.3	17.1	18.7	242	216	70
22/ 2/88	Cornwall Park Auckland	India Youth *vs* N.Z Youth	1	17.0	28.2	27.6	-	-	-
19/3/88	Eden Park No. 1 Auckland	N.Z. *vs* England	before	22.2	25.8	26.1	153	-	-
			after	20.5	26.6	26.9			

Plate 6.8 A well prepared pitch surface for the St John soil showing moderate cracking and the formation of large blocks between cracks.

The results obtained for the Auckland vs Wellington match on 13-15/1/88 (Table 6.5) show that if the St John soil is managed correctly it has the potential to produce an acceptable pitch for first class cricket. Soil moisture contents for this match were closer to those values measured on the trial plots (Appendix 6.11-6.14), and the pitch was described as excellent for a 3-day fixture. It was medium-paced and bounce was even, with spin developing on the third day (Match Report).

Despite the low binding strength value recorded for the St John soil (Table 5.1), pitch wear during these matches was acceptable. The wear that resulted, combined with the presence of controlled soil cracking, possibly contributed to the development of spin during the later stages of the Auckland *vs* Wellington match (13-15/1/88).

While properties of the St John soil may preclude it from producing fast-paced pitches for Test cricket, use of management techniques which develop maximum soil potential will allow acceptable and consistent results to be attained at first class level.

The differences in Palmerston North pitch soil water contents for fixtures on the 20/11/87 and the 10/2/88 may reflect the difficulty faced by groundsmen to achieve sufficient soil drying during November with less favourable weather and limited preparation periods (Section 6.3). The improved pitch management during the January preparation was probably largely a function of the longer preparation period used for the more important February fixture.

The performance of the Marton-local soil mix used on the Palmerston North pitch provides further justification for the selection of this soil type. The 3-4 week management programme used (pers. comm. K. Timms) allowed soil drying to depth and production of a hard surface. Furthermore, the high surface and subsurface penetration resistance values recorded (Table 6.5) compare favourably with those measured on the Palmerston North soil trial plots (Appendices 6.11-6.14). The greater average surface penetration resistance for the trial plots was probably due to higher soil bulk density levels developed during the 1986/87 and 1987/88 summers (Section 6.6). Bounce on the Palmerston North pitch at Fitzherbert Park could, therefore, possibly be further improved by altering the timing of rolling operations which increase soil density.

The low levels of soil moisture and high penetration values for the Central Districts *vs* Northern Districts fixture (Table 6.5) parallel the favourable pitch performance during the match. The pitch was medium-paced to quick with consistent bounce. Players rated it as the best pitch they had played on that season (pers. comm K. Timms) despite the fixture being rain-affected.

A change in the ratio of Marton-local soil mix by the groundsman also appeared to successfully counter the wear problems characteristic of this soil in the past (Plate 4.1). Improved wear tolerance, combined with the easily managed soil properties, and expertise of the groundsman, ensures the Palmerston North soil consistently produces high quality pitches for first class cricket.

<u>Conclusions</u>

1. Higher than desirable subsurface soil moisture contents reduced the performance of the St John soils on the pitches studied.

2. When the St John and Palmerston North soils were dried deeply and evenly to depth, pitches of acceptable standard for first class cricket were produced.

3. While the soil properties of the St John soil may preclude it from producing fast-paced pitches for Test cricket, use of management techniques which develop maximum soil potential will ensure acceptable results are obtained at the first class level.

4. Despite the low binding strength values recorded for the St John and Palmerston North soils, pitch wear during play was acceptable.

5. A combination of desirable soil properties and management expertise ensures that pitches of high standard are consistently produced on the Palmerston North soil.

6.9 Pitch soil infiltration and irrigation scheduling

Irrigation principles for pitch preparation deviate from the rules of 'normal' crop watering. In addition to applying water to meet the plant's needs, an irrigation schedule must fit the laws of soil mechanics and the soil engineering requirements. Further, the irrigation application rate must accomodate the constraints imposed by intensive surface preparation.

Mean infiltration rates for the pitch trial soils are shown in Table 6.6. The differences in infiltration rates reflect the extent of cracking present at the time of infiltration measurement (Day 5, Appendix 6.16). The moderate cracking associated with the limited swelling St John soil and the extensive to excessive cracking developed by the swelling type Ward and Kakanui soils facilitate preferential flow of water into and through the soil. In comparison, few water-transmitting macropores are present in the non swelling Palmerston North soil. The very high infiltration rate recorded for the Ward soil may be explained by the excessive amount of soil cracking present at time of measurement (Section 6.16). It could be expected that the infiltration rate would drop considerably once swelling closed cracks and steady state conditions were developed in this soil. Steady state conditions were approached in the Kakanui soil after 60 minutes with a subsequent reduction in measured soil infiltration rate (Appendix 6.20).

Irrigation of the cricket pitch aims to wet up the soil to a plastic state so that it can be remoulded by compaction to form a dense mass. In practice this has generally been achieved by applying water at high rates and in excess quantities to ensure saturation occurs. Table 6.7 shows the equivalent depths of water stored in the soils at field capacity (FC), and the total available water (TAW), readily available water (RAW), and optimum rolling available

Table 6.6 Mean infiltration rates of the pitch trial soils after 60 minutes of ponding (mm hr^{-1}).

Pitch Soil	Infiltration rate at t = 60 mins
Palmerston North	1.0
Ward	100
St John	9.0
Kakanui	8.0

Table 6.7 Equivalent depths of stored water (mm) for each of the pitch soils studied at field capacity (FC) together with the total available water (TAW) readily available water (RAW) and optimum rolling available water (ORAW).

Pitch Soil	FC	TAW[1]	ORAW[1]	RAW[1]
Palmerston North	50	25	14	10
Ward	54	24	15	12
St John	61	30	18	15
Kakanui	71	33	20	16

[1] Assumed effective rooting depth = 100 mm

water (ORAW) (Section 4.1). By combining infiltration rates in Table 6.6 with equivalent depths of soil water (Table 6.7), it is possible to predict the duration of ponding irrigation required to reach a particular level of soil moisture.

For example, assuming an infiltration rate of 1 mm hr^{-1} for the Palmerston North soil (Table 6.6) and 50 mm of water needing to be applied (Table 6.7) to reach field capacity, it would be necessary to continually irrigate for up to 2 days (dependent on extent of initial soil dryness). If the aim of irrigation is to transform the soil into a plastic mouldable state for rolling, there may be little point in applying water additional to that required to achieve optimum rolling efficiency (Section 4.5). For the Palmerston North soil only 14 mm of water (Table 6.7) would need to be applied, which corresponds to an irrigation duration of 14 hours. Water applied in excess of that needed to reach the optimal rolling condition is extra water which must be lost from the soil before match day, thereby necessitating a longer preparation period. This could be of particular relevance for lower grade cricket, where pitches must be prepared from week to week. Watering to optimum rolling point, in combination with an irrigation scheduling policy which ensures that water is applied to the pitch as soon after match day as is practicable, will provide greater opportunity for the development of a dry, hard pitch.

As well as ensuring greater accuracy in terms of amounts of water to be applied, a knowledge of infiltration rate also enables irrigation efficiency to be improved. By matching the water application rate with infiltration rate, surface runoff and water usage are minimised. Non swelling soils with lower infiltration rates (Table 6.6), will require lower rates of application.

Water application rate is a function of the design of the irrigation system. Sprinkler irrigation design shold aim to avoid surface ponding, as this can contribute to non-uniform infiltration and an uneven soil wetting depth. Uneven wetting is most effectively overcome by controlled application rate. Lower water application rates may be achieved by irrigation pulsing, or alternatively by using a microjet sprinkler system. Microjet sprinklers are, however, much affected by wind drift. One possible solution for major grounds (e.g. Test venues) could entail the development of a greenhouse structure for the pitch area. Unfortunately, the logistical cost and limitations of such a structure would restrict its application to Test cricket pitch preparation (Section 6.11).

Many irrigation systems currently in use on cricket pitches in New Zealand, apply water at excessive rates (> 10 mm hr^{-1}) and may need to be modified, especially where non swelling soils have been used for pitch construction (pers. comm. New Zealand Turf Culture Institute). The large droplet size characteristic of such systems may also cause surface damage, especially if bare patches exist on the pitch surface.

Water application rate will, however, be a trade-off between the 'ideal' and the 'practical'. High application rate systems characterised by large droplet size are less subject to the problems of wind drift. In addition, high application rates and watering to saturation could be policies used by many groundsmen at first class level as an insurance factor to ensure sufficient water is held in the soil at the start of preparation. It is also, perhaps a reflection of limited manpower, equipment and financial resources available at many first class venues. Watering to saturation would be an acceptable practice providing rolling is not carried out when the soil is too wet (Section 4.5), and adequate time is allowed during the preparation period for removal of excess water before match day.

A further function of the cricket pitch irrigation system is to provide small amounts of water frequently during preparation to help slow the rate of surface drying and relieve plant stress. In this study, pulses of 5 minutes duration (applying 0.5-1.0 mm depth) were used during the day to prolong water loss by evaporation, and in the evening to provide moisture for rolling the following morning. This type of irrigation procedure could be most effectively achieved through a microject system automatically programmed to mist the soil surface frequently during the early stages of preparation. This could prevent a steep moisture gradient developing at the surface, thereby reducing plant stress, ultimately resulting in improved water loss from depth. Reduction of surface drying rate may have contributed to improved water loss at depth measured during the second preparation periods of the field trial (Appendix 6.12; 6.14).

An important aspect of pitch irrigation is the prevention of lateral water seepage onto a prepared surface. The construction of sand slits (connected to the drainage layer) between individual pitches on a square may be necessary. These channels will prevent seepage when pitches adjacent to the match pitch are watered during preparation. Channels will also help minimise the risks of runoff from water moving under covers. For aesthetic reasons the slits could be capped by turf during periods of play.

Conclusions

1. A knowledge of soil infiltrability allows irrigation design to be coupled with pitch soil properties, thereby ensuring most efficient watering.

2. Combining soil infiltration rate with optimum rolling available water (ORAW) provides an estimate of the amount of water to be applied during irrigation and the length of time required to achieve such a soil water content.

3. Irrigation to optimum rolling water content is of particular value for lower grade cricket where time is a factor limiting the extent of soil drying during pitch preparation.

4. High application rates characteristic of many New Zealand pitch irrigation systems may cause surface ponding and uneven soil wetting to depth.

5. More efficient systems could utilise low volume applicators such as microjet sprinklers, or a management technique such as irrigation pulsing.

6. The rate of application by low volume sprinkler systems could be further modified to create surface misting during preparation, and would be well suited for applying small amounts of water to the pitch surface during the final stages of rolling.

7. Irrigation design must consider the financial and resource constraints in place at each venue. These constraints may limit the successful application of scientific principles.

8. The use of infiltrability data has limitations due to spatial and temporal variations in this parameter, but it does provide information for developing management programmes which can be fine-tuned by gravimetric water content sampling.

9. Irrigation system design and water movement in cricket pitches presents an area for further study, but research must provide practical application of scientific principles.

6.10 Off-season Management

The off-season management can have a major bearing on pitch performance during the following season.

One problem commonly encountered with cricket pitches is soil layering, whereby root development is curtailed at a cleavage plane. With a restricted rooting depth there is less opportunity for drying of the soil to depth. This will ultimately result in lower bounce.

A layering phenomenon was diagnosed on an existing Ward soil pitch in Blenheim in 1985. The cause of layering was probably largely due to poor incorporation of topdressing soil into existing soil during pitch renovation. Shallow layering and creation of a cleavage plane near the surface also occurred on the trial plots during the summer of 1985. Trial plot soil layering could possibly be explained by a combination of rolling before the grass plants had established roots to sufficient depth, and rolling while the surface layer was too dry. The turf-soil layer was removed and the plots extensively renovated by sub aeration and grooving in the autumn of 1986. Subair treatment was carried out when the plots were very dry to maximise the extent of soil cracking and associated compaction relief.

A common complaint regarding the use of a vibra-mole of sub-air is the subsequent development of continuous cracks coinciding with the leg slot of the implement. These cracks often stand out as green bands running the length of the pitch. The leg slot crack is most probably indicative of incorrect timing of the vibra-mole, whereby the soil is too wet (in a plastic state) to allow the development of tension cracks and soil shattering. Instead, the only effect observed is a slicing action, with the slot created re-opening over the following summer.

In the present study, the fact that the second preparation of the 1986/87 summer began within 6 weeks of the trial plots being sub-aired and renovated illustrates that it is possible to obtain a good pitch following an extensive spring renovation.

Conclusions

1. Regular physical treatment of non swelling and limited swelling soils is important to alleviate the detrimental effects of soil compaction on water and air movement, and plant growth.

2. The creation of macropores to depth can only be achieved if such physical treatment is carried out at the correct soil water content.

3. While other physical treatments such as grooving and coring (not a part of this study) have important roles in spring and autumn renovation of pitches, especially on dual use grounds, they provide minimal compaction relief.

6.11 A Greenhouse Structure for Test Cricket

The management of Test cricket pitches must be different to that used for preparation of first class pitches. While the principles of pitch preparation are similar, the importance of Test cricket, both from a financial and spectacle viewpoint, creates increased demands. Every safeguard must be taken to prevent failure or the production of a sub-standard playing surface.

Many of the problems associated with pitch management occur as a result of inclement weather. By utilising a greenhouse structure over the pitch area, complete control of the environment could be achieved during pitch preparation. Such a structure would have many benefits including:

1. The groundsman would be able to continue pitch preparation despite inclement weather in the lead up to a match. While covers may keep rain off a pitch they reduce management flexibility for operations such as rolling and this can lead to underpreparation of the pitch before an important fixture.

2. It would be possible to raise air and soil temperatures after pitch renovation in spring and autumn, thus promoting better grass establishment and cover development in otherwise potentially marginal weather.

3. It would allow the use of micro sprinklers for irrigation of non swelling soils and the reduction of surface evaporation rate by eliminating the problem of wind drift.

4. It would permit the further reduction of surface evaporation rate when required in the early stages of preparation through use of shade cloth in conjunction with the greenhouse structure.

5. It would provide opportunity for artificial heating to promote more rapid soil drying during periods of inclement weather.

6. It would provide complete protection of the pitch area and surrounds from rain and prevent water seepage onto the prepared pitch, which can be a problem associated with other cover systems during preparation.

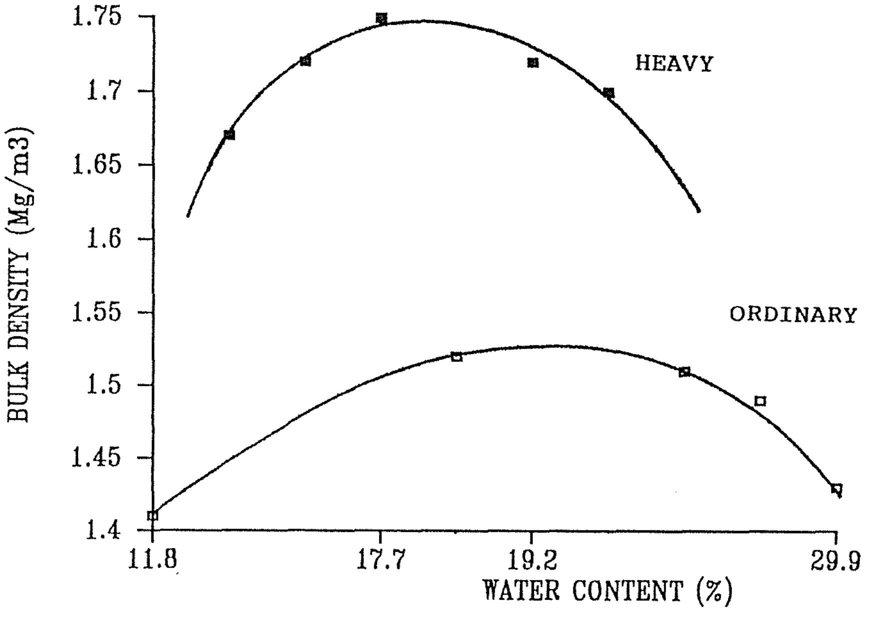
Conclusions

1. While combining the benefits of engineering, agronomic, and soil principles, the greenhouse structure would need to provide flexibility and mobility.

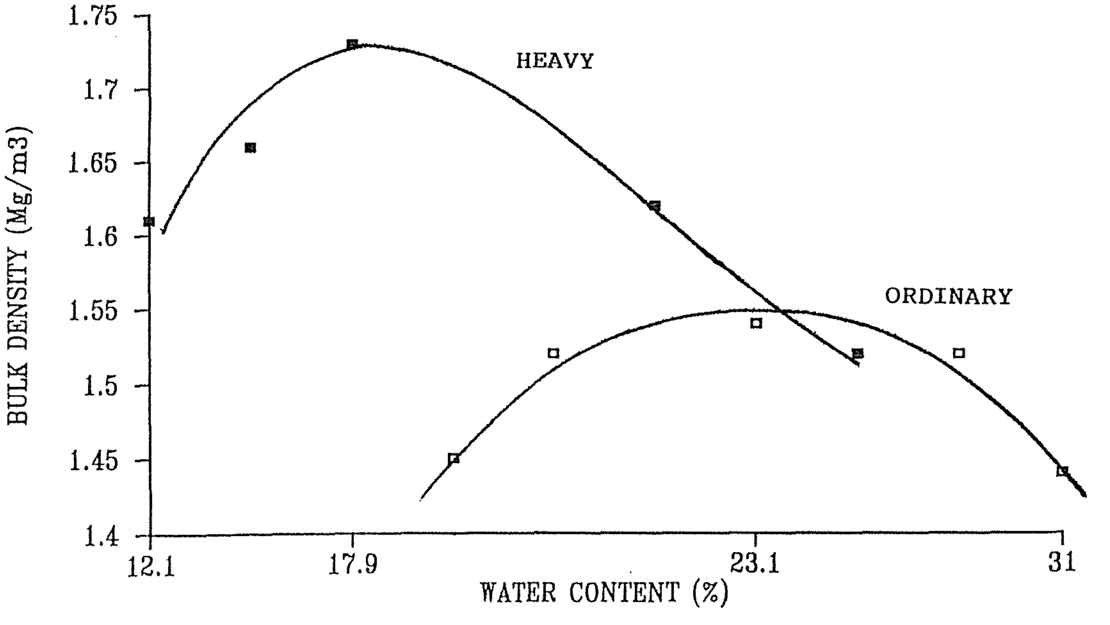
2. A greenhouse structure would require significant capital expenditure but this concept, in light of increasing demand for superior playing surfaces from players, spectators, and administrators alike, could be a feasible option for New Zealand Test venues and would allow the ultimate application of scientific principles to pitch preparation.

APPENDICES

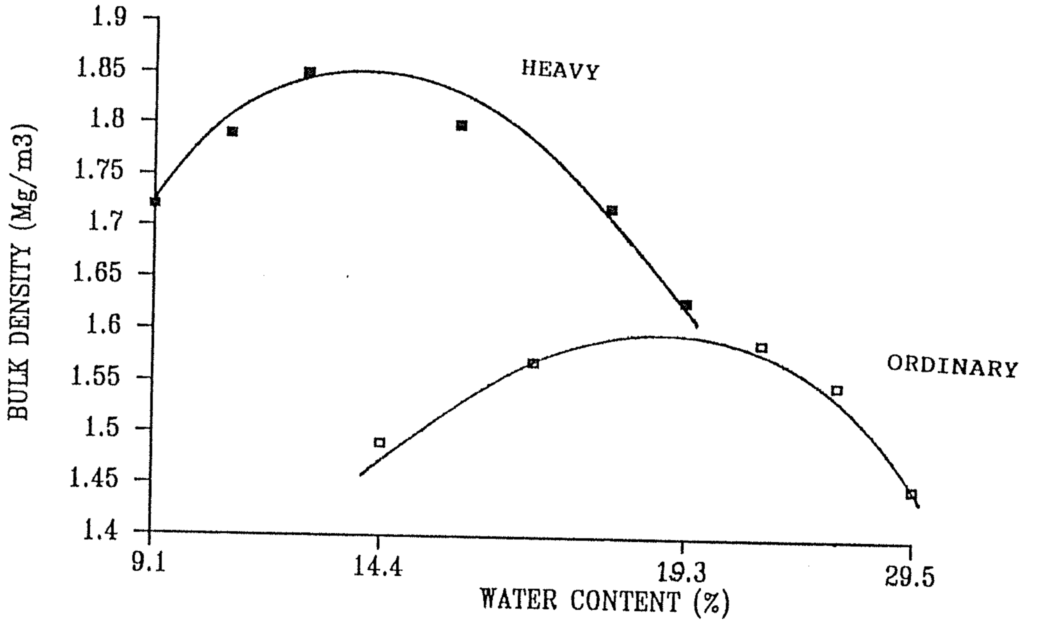
Appendix 4.1 Ordinary and heavy Proctor compaction curves determined for the Marton soil.



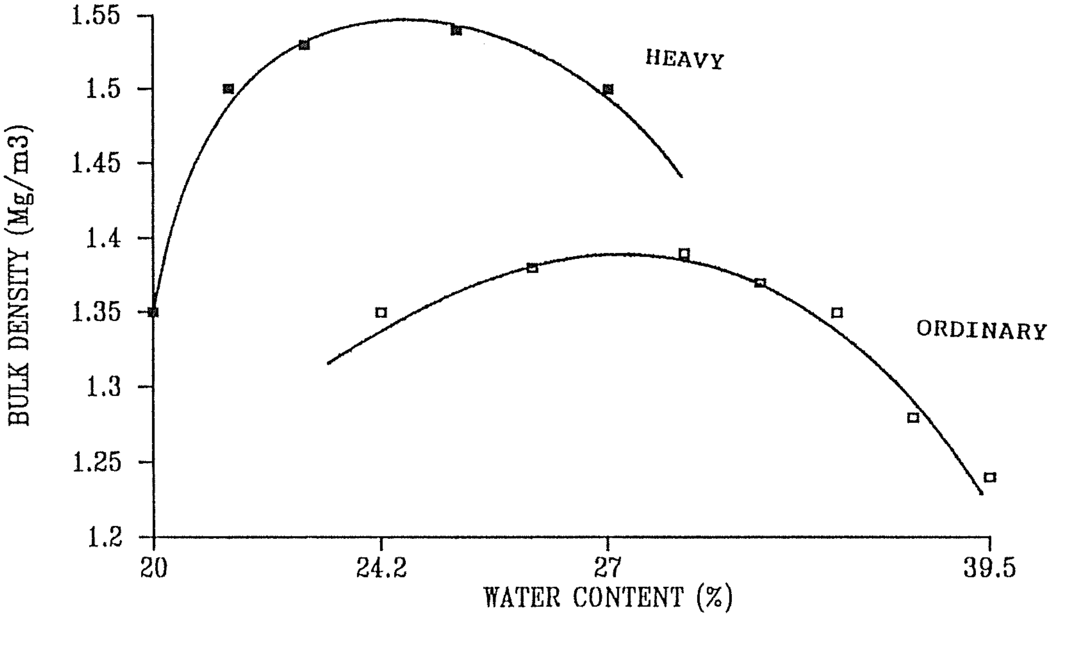
Appendix 4.2 Ordinary and heavy Proctor compaction curves determined for the St John soil.



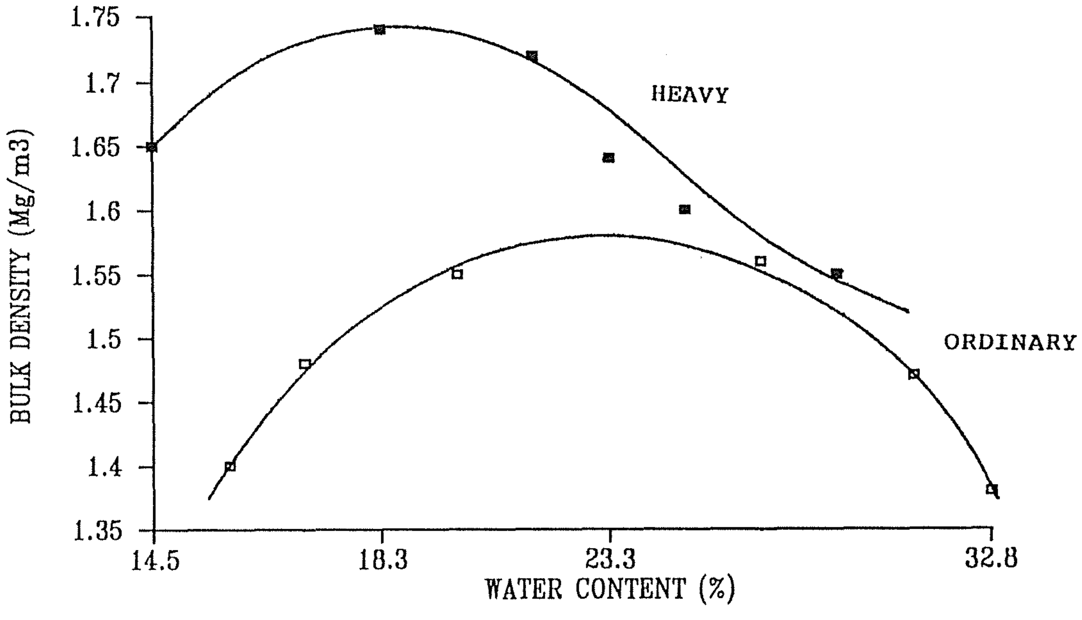
Appendix 4.3 Ordinary and heavy Proctor compaction curves determined for the Palmerston North soil.



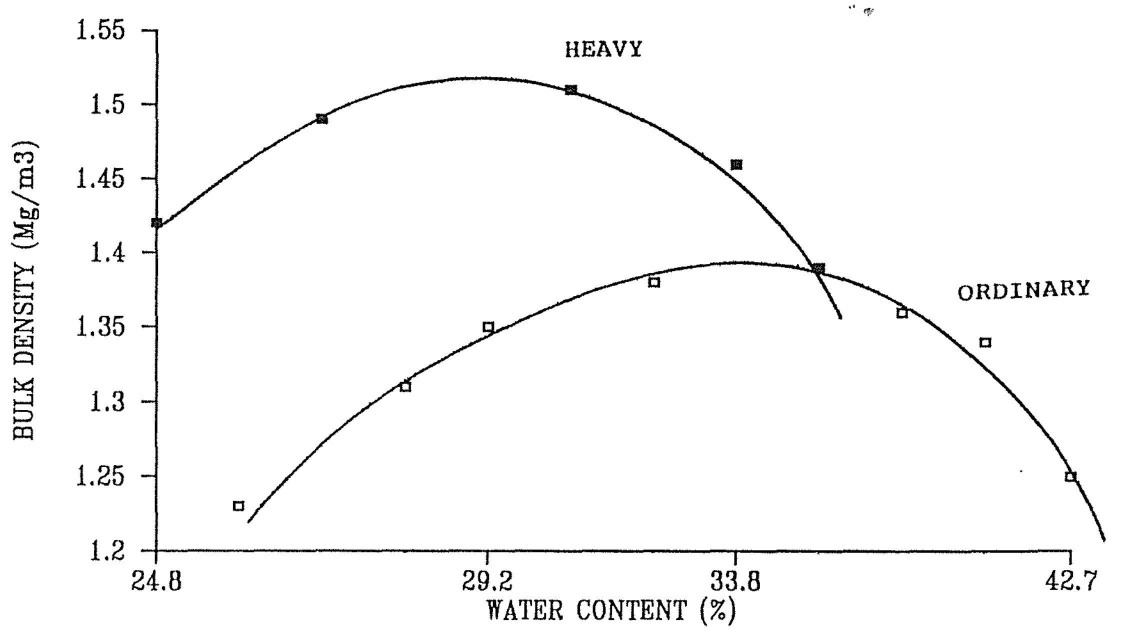
Appendix 4.4 Ordinary and heavy Proctor compaction curves determined for the Ward soil.



Appendix 4.5 Ordinary and heavy Proctor compaction curves determined for the Kakanui soil.



Appendix 4.6 Ordinary and heavy Proctor compaction curves determined for the Redhill soil.



APPENDIX 4.7 The relationship between compaction achieved by the Proctor test and the action of a roller in the field.

Surface Contact Area [1] [2] (metres)	Pressure Applied (k Pa)				
	Mass of Roller (kg)			Proctor Compaction	
	500	1000	1500	Ordinary	Heavy
0.05	98	196	294	50	90
0.1	49	90[3]	147	50	90
0.2	25	49[3]	74	50	90
0.3	16	33	49	50	90

[1] Assume roller 1 metre wide

[2] Dependent on roller diameter and soil water content

[3] Roller mass/surface contact area combinations commonly used during the field trial.

APPENDIX 6.1 Procedure and worksheet for gravimetric water content sampling and pitch soil water content determination.

STEP 1. Using the soil corer, take two soil cores (one from each end of the pitch), each to a depth of 25 mm.
Immediately put the cores into separate labelled plastic containers, making sure the lids are closed tightly.

STEP 2. Place the corer back into each hole and take two more soil cores 25 mm long i.e. from 25-50 mm depth.
Once again, immediately put the cores into two more labelled plastic containers.

STEP 3. Repeat Step 2 and collect soil cores for the depth 50-75 mm using two more plastic bottles.
N.B. There should be 6 plastic containers with soil cores for each testing day.

STEP 4. Weigh each container with the soil inside and lid on. Record the mass (m_1). Remove the lid, sit the bottle on the lid and place in the oven overnight at 105°C.

STEP 5. Remove each container from the oven, screw the lids back on immediately and record the mass (m_2).
Empty the soil core(s) from each container, replace the lids, weigh each empty container plus lid and record the mass (m_3).

STEP 6. Calculate the water content:

$$\text{water content } (\%) = \frac{m_1 - m_2}{m_2 - m_3} \times 100(\%)$$

GRAVIMETRIC WATER CONTENT

VENUE: ....

MATCH: ....v.......................

DATE: ....

Soil Depth	0-25 mm	25-50 mm	50-75 mm
Wet soil and container (m_1) (g)			
Dry soil and container (m_2) (g)			
Container (m_3) (g)			
Water content (w) $\frac{m_1 - m_2}{m_2 - m_3} \times 100$ (%)			

APPENDIX 6.2 Trial plot management programme for the first preparation of 1986/87.

Date	Day	Irrigation (hours)	Rainfall (mm)	Rolling	Maximum Temperature (°C)	Sunshine (hours)	PET (mm)
1/12/86	1			6x	14.8	2.5	3.1
2/12/86	2		0.1		15.6	4.5	3.3
3/12/86	3				16.6	1.9	3.3
4/12/86	4				16.7	1.6	2.9
5/12/86	5	7 hours			20.5	12.2	7.6
6/12/86	6*	8½ hours		6x	20.2	9.2	6.0
7/12/86	7				17.3	2.5	4.0
8/12/86	8	5 hours		24x	18.0	4.7	4.5
9/12/86	9			12x	18.1	3.1	4.3
10/12/86	10				18.3	2.6	5.2
11/12/86	11				22.1	12.5	6.0
12/12/86	12*	15 hours		24x	23.5	12.7	6.5
13/12/86	13				23.7	11.5	7.0
14/12/86	14		0.4		24.6	8.1	8.5
15/12/86	15				23.0	3.5	4.3
16/12/86	16		9.4		22.1	0.0	3.2
17/12/86	17				25.3	6.8	5.5
18/12/86	18				24.7	6.9	7.9
19/12/86	19				23.9	4.7	0.0
20/12/86	20				24.9	3.3	6.8
21/12/86	21		8.1		23.4	0.0	0.6
22/12/86	22		0.2		19.3	0.9	2.2
23/12/86	23*	MATCH DAY	0.2		22.6	7.5	6.6
24/12/86	24	Renovation					

* Testing day

APPENDIX 6.3 Trial plot management programme for the second preparation of 1986/87.

Date	Day	Irrigation (hours)	Rainfall (mm)	Rolling	Maximum Temperature (°C)	Sunshine (hours)	PET (mm)
31/1/87	1	6 hours	2.0		22.7	8.0	6.1
1/2/87	2	12 hours			23.9	11.4	8.1
2/2/87	3*	5 min		8x	23.5	4.3	7.6
3/2/87	4	5 min	0.2	8x	23.0	9.6	5.6
4/2/87	5	5 min	8.6	8x	25.9	5.6	8.1
5/2/87	6	10 min			21.5	8.1	8.0
6/2/87	7	5 min			20.6	12.7	8.0
7/2/87	8	5 min am pm	20.9		22.5	3.7	2.9
8/2/87	9			8x	18.1	4.5	3.0
9/2/87	10	5 min am pm			19.6	12.3	4.4
10/2/87	11	5 min		6x	25.0	10.9	5.7
11/2/87	12*				24.1	10.0	6.0
12/2/87	13	5 min	0.2	6x	23.7	10.1	6.2
13/2/87	14	5 min	2.7		20.6	5.3	4.2
14/2/87	15	5 min	4.2	8x	17.5	3.6	3.0
15/2/87	16		13.5		18.6	2.5	1.4
16/2/87	17*				19.6	3.5	3.5
17/2/87	18		1.5		20.6	5.5	3.4
18/2/87	19*		7.9		15.5	0.6	1.5
19/2/87	20				18.7	11	5.1
20/2/87	21				22.7	11.5	4.3
21/2/87	22				20.9	5.0	6.0
22/2/87	23		0.7	6x	22.2	10.7	5.3
23/2/87	24*	MATCH DAY			24.1	2.5	2.2
24/2/87	25				24.0	10.7	6.2
25/12/87	26*	MATCH END			23.0	12.4	6.1

* Testing Day

APPENDIX 6.4 Trial plot management programme for the first preparation of 1987/88.

Date	Day	Irrigation (hours)	Rainfall (mm)	Rolling	Maximum Temperature (°C)	Sunshine (hours)	PET (mm)
2/11/87	1	24 hours			16.0	0.0	2.0
3/11/87	2	12 hours			19.7	6.7	5.8
4/11/87	3	5 min			19.3	1.2	5.0
5/11/87	4*		0.9	20x	19.2	11.4	4.9
6/11/87	5				19.7	8.4	4.5
7/11/87	6		0.5		20.4	7.0	6.0
8/11/87	7				19.8	2.4	3.7
9/11/87	8		3.7	20x	23.5	12.4	5.8
10/11/87	9				20.6	3.0	1.8
11/11/87	10		3.0	15x	17.6	1.0	3.6
12/11/87	11				20.8	7.7	4.6
13/11/87	12*	5 min	12.8	10x	23.6	2.9	2.0
14/11/87	13		11.3		21.3	0.1	3.8
15/11/87	14				17.1	10.5	6.9
16/11/87	15				16.9	10.1	6.0
17/11/87	16		0.5	10x	15.1	11.2	5.5
18/11/87	17				15.1	9.1	5.1
19/11/87	18				16.9	11.1	6.0
20/11/87	19*	MATCH DAY			20.3	12.6	6.2

* Testing Day

APPENDIX 6.5 Trial plot management programme for the second preparation of 1987/88

Date	Day	Irrigation (hours)	Rainfall (mm)	Rolling	Maximum Temperature (°C)	Sunshine (hours)	PET (mm)
20/1/88	1*				19.4	7.7	7.0
21/1/88	2				20.1	8.8	5.2
22/1/88	3	5 hours			22.9	12.0	5.2
23/1/88	4	24 hours			24.1	13.0	6.6
24/1/88	5	24 hours			25.1	12.8	7.0
25/1/88	6	12 hours			26.1	13.0	8.6
26/1/88	7	10 min		15x	25.2	10.7	7.0
27/1/88	8	5 min		10x	24.6	12.8	7.0
28/1/88	9	5 min		7x	24.4	3.9	3.9
29/1/88	10	5 min		7x	24.2	12.5	6.6
30/1/88	11				26.0	5.6	5.0
31/1/88	12*	10 min		7x	24.1	7.3	7.2
1/2/88	13			10x	24.8	5.8	5.9
2/2/88	14	5 min			25.1	9.2	6.3
3/2/88	15	5 min			26.2	2.5	5.1
4/2/88	16		6.0		22.0	0.0	2.3
5/2/88	17		12.6		18.3	2.5	1.4
6/2/88	18		9.5		23.7	6.5	4.6
7/2/88	19		19.7		23.3	1.7	3.7
8/2/88	20*		8.1		21.7	0.0	0.1
9/2/88	21			5x	26.3	12.8	7.3
10/2/88	22		0.2		27.8	8.2	6.9
11/2/88	23		27.0		27.2	1.6	2.1
12/2/88	24		14.0		29.0	8.8	4.4
13/2/88	25		7.0		29.2	6.1	5.0
14/2/88	26		5.9		27.7	4.0	4.5
15/2/88	27		7.6		27.8	5.0	4.3
16/2/88	28		1.5		26.4	5.3	2.9
17/2/88	29		3.0		22.2	0.5	3.0
18/2/88	30		3.1		17.0	0.0	0.1
19/2/88	31			7x	21.2	7.2	1.9
20/2/88	32		7.1		21.9	3.6	3.6

21/2/88	33		10.5		18.7	2.6	4.1
22/2/88	34		1.0		19.0	6.9	4.7
23/2/88	35			7x	21.1	2.3	6.9
24/2/88	36		3.6		19.1	8.4	5.8
25/2/88	37		1.7		17.5	5.0	3.5
26/2/88	38			10x	18.0	8.9	4.6
27/2/88	39			30 min[1]	19.6	4.9	3.9
28/2/88	40		0.2	30 min	21.7	2.5	5.3
1/3/88	41		0.6	30 min	21.4	2.3	2.9
2/3/88	42				19.9	7.8	3.4
3/3/88	43				24.5	11.4	4.0
4/3/88	44*	MATCH DAY		30 min	26.4	11.7	4.7

[1] Surface preparation rolling

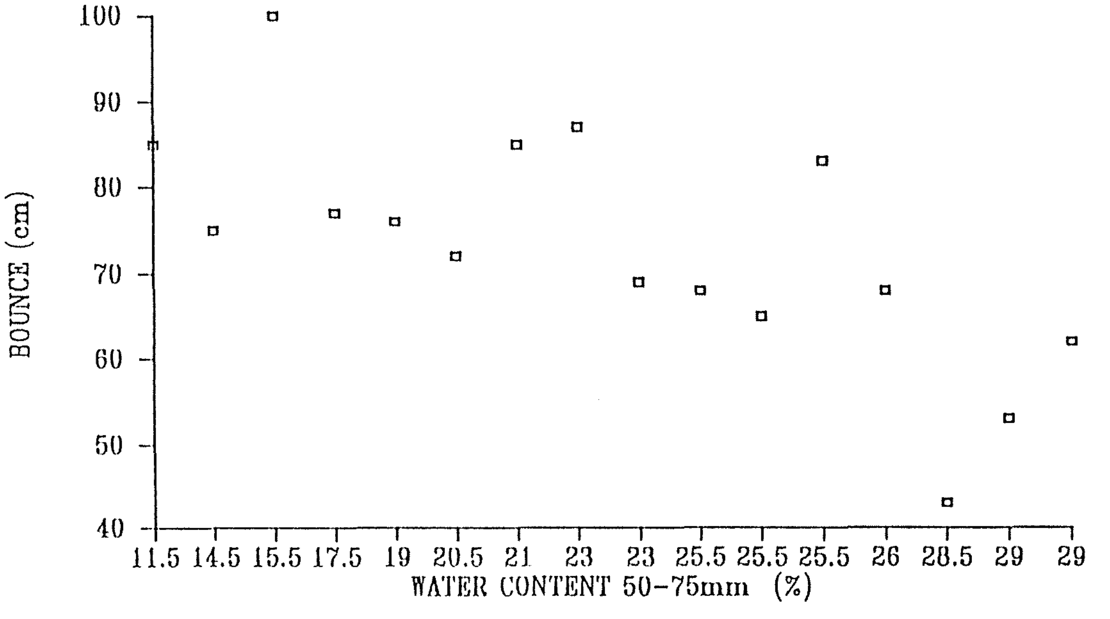
* Testing Day

APPENDIX 6.6 Match day correlations for water content and bounce, and hardness and bounce for 1986/87 and 1987/88 trial plot preparations.

Preparation	Soil water content Depth Determinant of Bounce (mm)	Correlation Coefficient	Soil Hardness Depth Determinant of Bounce (mm)	Correlation Coefficient
First 1986/87	25-50	-0.91	25-50	0.87
Second 1986/87	50-75	-0.65	0-25	0.68
First 1987/88	25-50	-0.73	0-25	0.66
Second 1987/88	25-50	-0.81	25-50	0.80

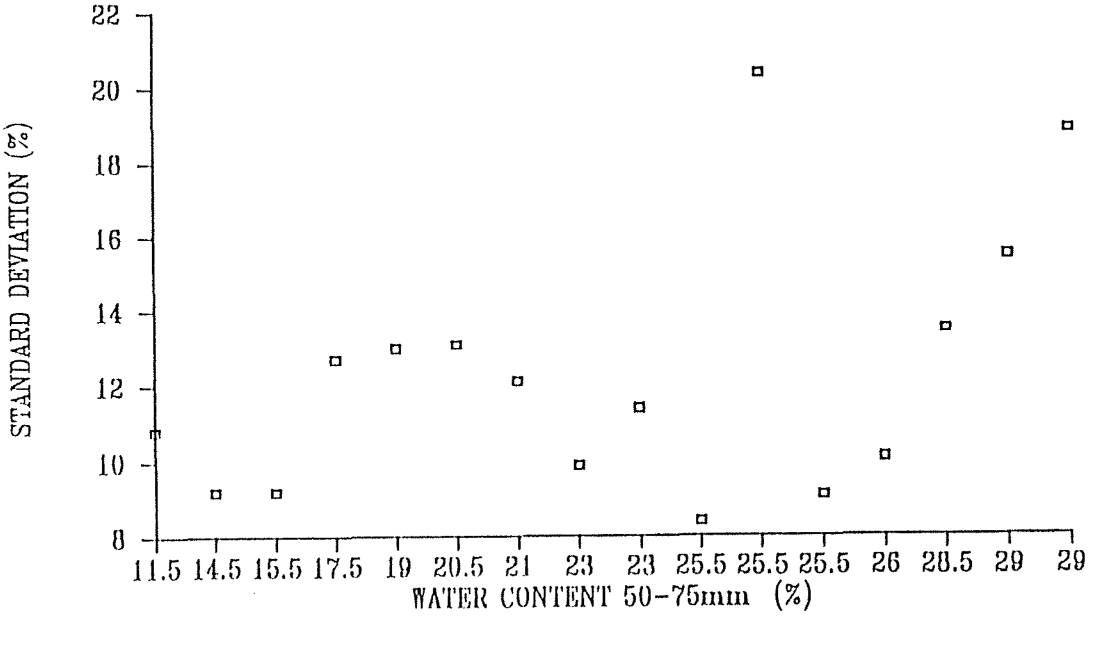
Appendix 6.7 The influence of soil water content at depth (50-75 mm) on the height of rebound bounce for the pitch soil depth-base treatment combinations on match day of the second preparation of 1986/87.

Y = 110.9 - 1.67 x



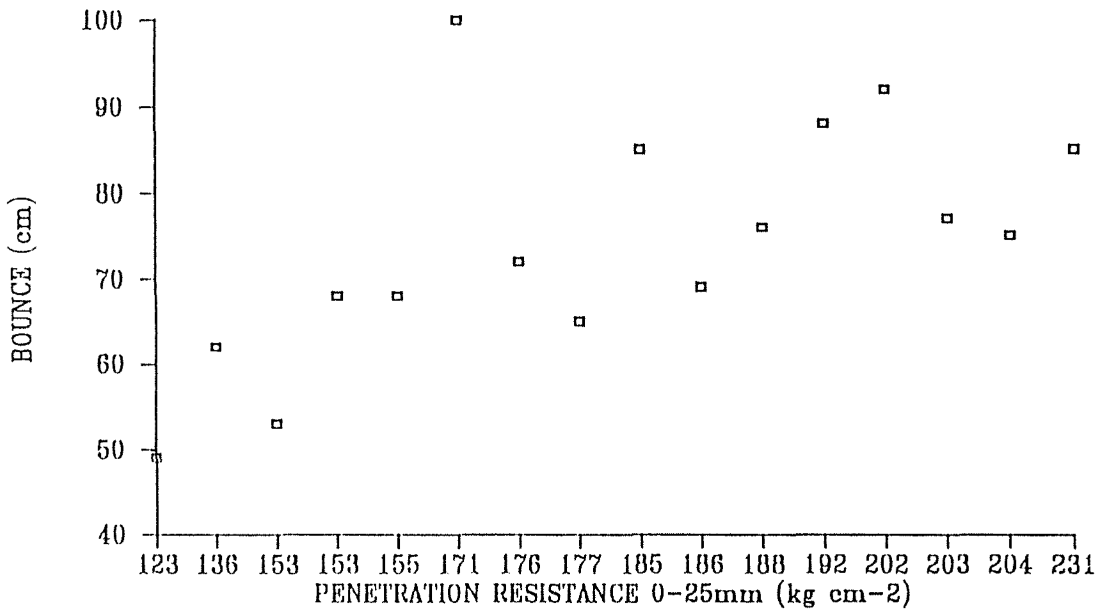
Appendix 6.8 The influence of soil water content at depth (50-75 mm) on the variability of rebound bounce for the pitch soil depth-base treatment combination on match day of the second preparation of 1986/87.

Y = 6.13 + 0.28 x



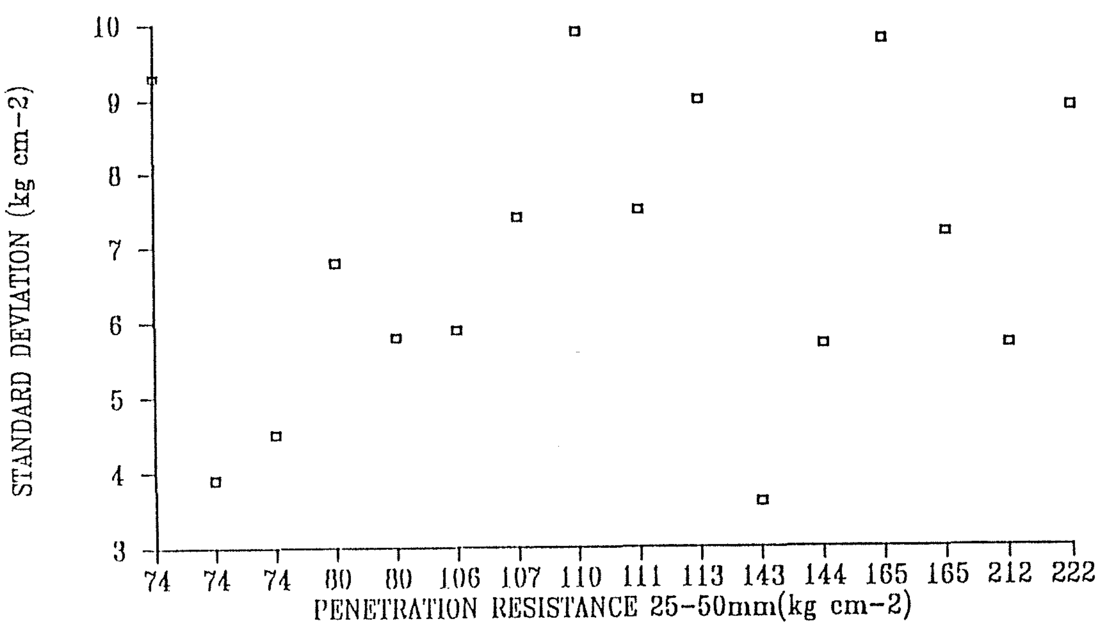
Appendix 6.9 The influence of soil hardness (0-25 mm) on the height of rebound bounce for the pitch soil depth-base treatment combinations on match day of the second preparation of 1986/87.

Y = 15.1 + 0.33 x



Appendix 6.10 The influence of soil hardness (25-50 mm) on the variability of rebound bounce for the pitch soil depth-base treatment combination on match day of the second preparation of 1987/88.

Y = 4.9 + 0.02 x



Appendix 6.11 Soil water content (0-25 mm, 25-50 mm), penetration resistance (0-25 mm, 25-50 mm), and rebound bounce for match day of the first preparation of 1986/87.

Trial soil depth-base combination	Water content (%) 0-25 mm	Water content (%) 25-50 mm	Water content (%) 50-75 mm	Penetration Resistance ($kg\ cm^{-2}$) 0-25 mm	Penetration Resistance ($kg\ cm^{-2}$) 25-50 mm	Bounce (cm)
Palmerston North						
50 mm sand	13.3 ± 0.8*	15.4 ± 1.3*		216 ± 31[a]	99 + 14[a]	53 ± 11.1[a]
50 mm soil	19.6 ± 2.7	20.6 ± 1.4		160 ± 53	61 ± 24	41 ± 8.7
150 mm sand	14.9 ± 1.1*	14.0 ± 0.0*		191 ± 41	113 ± 36[a]	60 ± 14.9[a b]
150 mm soil	17.5 ± 1.3	18.8 ± 0.0		193 ± 37	63 ± 23	47 ± 11.8
Ward						
50 mm sand	18.9 ± 0.9*	26.7 ± 0.8		148 ± 27	45 ± 11	31 ± 6.2
50 mm soil	23.7 ± 0.3	29.6 ± 0.4		139 ± 21	43 ± 8	28 ± 5.6
150 mm sand	21.2 ± 0.0	28.7 ± 0.2		148 ± 42	32 ± 9	37 ± 9.9
150 mm soil	23.2 ± 0.1	28.0 ± 1.6		139 ± 18	43 ± 17	38 ± 7.8
St. Johns						
50 mm sand	14.7 ± 1.1*	19.5 ± 1.8		203 ± 34	86 ± 16[a]	46 ± 11.1
50 mm soil	17.8 ± 1.0	21.9 ± 1.8		183 ± 51	63 ± 16	45 ± 15.0
150 mm sand	18.7 ± 0.8	22.3 ± 0.9		216 ± 30	57 ± 17	39 ± 8.7
150 mm soil	19.4 ± 1.3	23.3 ± 0.8		193 ± 25	47 ± 17	41 ± 10.4
Kakanui						
50 mm sand	18.0 ± 1.3*	23.0 ± 1.3*		205 ± 42	70 ± 21	44 ± 11.1
50 mm soil	23.0 ± 0.0	28.0 ± 0.1		137 ± 16	36 ± 18	25 ± 5.6
150 mm sand	19.5 ± 1.4	24.5 ± 1.7		185 ± 30	65 ± 27	33 ± 8.5
150 mm soil	21.5 ± 1.3	28.0 ± 1.1*		169 ± 19	43 ± 17	32 ± 8.6

* Significantly different from soil base ($P < 0.05$)

[a] Significantly different from Ward ($P < 0.05$)

[b] Significantly different from Kakanui ($P < 0.05$)

Appendix 6.12 Soil water content (0-25 mm, 25-50 mm, 50-75 mm), penetration resistance (0-25 mm, 25-50 mm) and rebound bounce for match day of the second preparation of 1986/87.

Trial soil depth-base combination	Water content(%) 0-25 mm	Water content(%) 25-50 mm	Water content(%) 50-75 mm	Penetration Resistance (kg cm^{-2}) 0-25 mm	Penetration Resistance (kg cm^{-2}) 25-50 mm	Bounce (cm)
Palmerston North						
50 mm sand	10.0 ± 1.0*	15.5 ± 0.5*	11.5 ± 1.5*	231 ± 4[a]	218 + 16[a b]	85 ± 10.8
50 mm soil	18.5 ± 2.5	19.5 ± 0.5	21.0 ± 3.0	185 ± 38	105 ± 13[b]	85 ± 12.1
150 mm sand	13.5 ± 2.5	15.5 ± 2.5	15.5 ± 3.5	171 ± 51	114 ± 47	100 ± 9.2[a b]
150 mm soil	17.0 ± 2.0	17.0 ± 3.0	20.5 ± 2.5	176 ± 28	106 ± 19	72 ± 13.1
Ward						
50 mm sand	16.0 ± 0.0*	19.0 ± 1.0*	19.0 ± 0.0*	188 ± 30	121 ± 27	76 ± 13.0
50 mm soil	22.5 ± 0.5	28.0 ± 3.0	29.0 ± 1.0	136 ± 26	81 ± 30	62 ± 18.9
150 mm sand	22.0 ± 1.0	28.0 ± 2.0	25.5 ± 7.5	153 ± 31	111 ± 22	68 ± 9.1
150 mm soil	25.0 ± 1.0	28.0 ± 0.0	23.0 ± 6.0	186 ± 18	111 ± 13	69 ± 11.48
St. Johns						
50 mm sand	11.0 ± 2.0*	15.5 ± 1.5*	14.5 ± 3.5*	204 ± 22	155 ± 27	75 ± 9.2
50 mm soil	20.5 ± 0.5	21.0 ± 0.0	25.5 ± 0.5	177 ± 28	98 ± 15	65 ± 20.4
150 mm sand	17.0 ± 0.5	22.0 ± 1.0	23.0 ± 2.0	202 ± 32	126 ± 20	78 ± 9.9
150 mm soil	19.0 ± 2.0	23.0 ± -	25.5 ± 1.5	192 ± 38	175 ± 11[a b]	83 ± 8.4[b]
Kakanui						
50 mm sand	13.5 ± 0.5*	27.0 ± 0.0	17.5 ± 0.5*	203 ± 37	100 ± 12	77 ± 12.7
50 mm soil	20.0 ± 2.0	27.0 ± 0.0	28.5 ± 1.5	123 ± 29	59 ± 12	49 ± 13.5
150 mm sand	18.5 ± 2.5	22.5 ± 1.5	26.0 ± 2.0	155 ± 42	108 ± 19	68 ± 10.1
150 mm soil	22.0 ± 2.0	25.5 ± 1.5	29.0 ± -	153 ± 43	72 ± 9	53 ± 15.5

* Significantly different from soil base ($P < 0.05$)

[a] Significantly different from Ward ($P < 0.05$)

[b] Significantly different from Kakanui ($P < 0.05$)

Appendix 6.13 Soil water content (0-25 mm, 25-50 mm, 50-75 mm), penetration resistance (0-25 mm, 25-50 mm) and rebound bounce for match day of the first preparation of 1987/88.

Trial soil depth-base combination	Water content(%) 0-25 mm	Water content(%) 25-50 mm	Water content(%) 50-75 mm	Penetration Resistance (kg cm-2) 0-25 mm	Penetration Resistance (kg cm-2) 25-50 mm	Bounce (cm)
Palmerston North						
50 mm sand	15.7 ± 0.7 *	12.8 ± 0.2 *	15.0 ± 0.4 *	226 ± 16[a]	175 + 22[a b]	56 ± 7.3
50 mm soil	19.9 ± 1.7	18.0 ± 1.6	21.8 ± 0.7	187 ± 37[b]	136 ± 19	52 ± 4.7
150 mm sand	18.5 ± 3.4	18.8 ± 3.6	24.8 ± 3.5	190 ± 35	106 ± 49	62 ± 8.7
150 mm soil	19.0 ± 0.9	16.9 ± 0.5	19.9 ± 0.6	181 ± 32[a]	127 ± 27	54 ± 8.1
Ward						
50 mm sand	24.0 ± 2.2	24.0 ± 2.4	23.0 ± 0.2 *	141 ± 21	118 ± 21	36 ± 8.8
50 mm soil	25.1 ± 0.6	25.8 ± 0.1	26.9 ± 3.2	122 ± 19	111 ± 18	41 ± 7.1
150 mm sand	25.3 ± 0.4	24.6 ± 0.8	27.7 ± 0.0	139 ± 19	124 ± 18	46 ± 7.2
150 mm soil	26.5 ± 1.1	25.5 ± 0.5	27.0 ± 1.7	103 ± 14	113 ± 23	38 ± 10.6
St. Johns						
50 mm sand	17.4 ± 1.7*	17.4 ± 1.7*	17.0 ± 1.0 *	225 ± 16	133 ± 32	47 ± 8.5
50 mm soil	21.1 ± 0.6	21.9 ± 1.3	23.1 ± 0.8	188 ± 28	157 ± 35	45 ± 8.4
150 mm sand	20.1 ± 0.5	19.9 ± 0.5	21.1 ± 0.0	201 ± 21	144 ± 32	43 ± 9.9
150 mm soil	20.6 ± 0.1	21.0 ± 0.1	23.3 ± 0.6	173 ± 37	122 ± 22	41 ± 7.9
Kakanui						
50 mm sand	19.0 ± 1.1*	29.8 ± 0.9	18.4 ± 1.8*	208 ± 28	108 ± 10	46 ± 10
50 mm soil	23.0 ± 0.3	24.2 ± 0.2	25.9 ± 1.5	110 ± 12	100 ± 19	32 ± 4.6
150 mm sand	20.8 ± 0.8*	20.8 ± 0.9	23.6 ± 0.8	143 ± 14	123 ± 21	46 ± 7.5
150 mm soil	23.2 ± 0.2	21.0 ± 0.1	25.6 ± 0.2	129 ± 17	106 ± 31	38 ± 6.8

* Significantly different from soil base ($P < 0.05$)

[a] Significantly different from Ward ($P < 0.05$)

[b] Significantly different from Kakanui ($P < 0.05$)

Appendix 6.14 Soil water content (0-25 mm, 25-50 mm, 50-75 mm), penetration resistance (0-25 mm, 25-50 mm) and rebound bounce for match day of the second preparation of 1987/88.

Trial soil depth-base combination	Water content(%) 0-25 mm	Water content(%) 25-50 mm	Water content(%) 50-75 mm	Penetration Resistance ($kg\ cm^{-2}$) 0-25 mm	Penetration Resistance ($kg\ cm^{-2}$) 25-50 mm	Bounce (cm)
Palmerston North						
50 mm sand	12.2 ± 0.8	12.6 ± 0.1*	13.3 ± 0.8 *	309 ± 51 [a,b]	212 + 63 [a]	69 ± 9.5 [a,b]
50 mm soil	14.4 ± 0.9	17.7 ± 1.3	19.7 ± 1.3	263 ± 48 [a,b]	144 ± 32 [b]	70 ± 5.7 [a,b]
150 mm sand	14.0 ± 2.4	15.2 ± 1.9	17.3 ± 1.3	289 ± 44 [b]	222 ± 39 [a,b]	75 ± 8.9 [a,b]
150 mm soil	14.4 ± 0.8	16.1 ± 0.2	18.2 ± 0.5	243 ± 34	165 ± 29 [b]	66 ± 7.2 [a,b]
Ward						
50 mm sand	19.6 ± 0.7	22.2 ± 1.4*	23.7 ± 1.0 *	166 ± 37	110 ± 19	43 ± 9.9
50 mm soil	21.5 ± 2.6	24.6 ± 0.9	29.9 ± 0.3	157 ± 30	107 ± 21	35 ± 7.4
150 mm sand	21.6 ± 0.3	25.8 ± 0.4	27.2 ± 0.4	203 ± 52	106 ± 14	45 ± 5.9
150 mm soil	20.7 ± 1.3	25.1 ± 0.3	27.9 ± 0.1	192 ± 22	111 ± 21	48 ± 7.5
St. Johns						
50 mm sand	14.4 ± 0.5 *	18.1 ± 0.9*	20.1 ± 1.7 *	274 ± 67	143 ± 43	52 ± 3.6
50 mm soil	17.7 ± 0.9	20.9 ± 0.0	24.2 ± 0.8	245 ± 56	74 ± 11	49 ± 9.3
150 mm sand	16.7 ± 1.0	20.9 ± 0.5	23.3 ± 0.5	317 ± 52 [b]	80 ± 20	53 ± 6.8
150 mm soil	17.2 ± 0.8	21.3 ± 0.0	23.6 ± 0.8	255 ± 32	165 ± 37 [b]	55 ± 9.8
Kakanui						
50 mm sand	15.0 ± 0.1*	19.1 ± 0.3 *	19.6 ± 0.5 *	192 ± 53	113 ± 27	39 ± 9.0
50 mm soil	16.9 ± 1.2	25.3 ± 0.5	30.7 ± 0.6	164 ± 37	74 ± 11	32 ± 4.5
150 mm sand	17.4 ± 0.2	23.1 ± 1.3	27.3 ± 1.2	169 ± 43	80 ± 20	45 ± 5.8
150 mm soil	16.1 ± 0.6	24.6 ± 0.2	28.2 ± 0.5	212 ± 39	74 ± 19	44 ± 3.9

* Significantly different from soil base ($P < 0.05$)

[a] Significantly different from Ward ($P < 0.05$)

[b] Significantly different from Kakanui ($P < 0.05$)

Appendix 6.15 Speed test assessment of the trial plot soils on match day of the second preparation of 1986/87 and 1987/88.

Soil Base Depth Combination	Velocity[1] off the pitch (kph)		Rebound height[1] at 3 metres (cm)	
	1986/87	1987/88	1986/87	1987/88
Palmerston North				
50 mm Sand	75	62	67	83
50 mm Soil	78	60	83	74
150 mm Sand	75	56	82	88
150 mm Soil	72	59	75	76
Ward				
50 mm Sand	79	53	60	73
50 mm Soil	73	54	65	63
150 mm Sand	n.d.	53	n.d.	87
150 mm Soil	n.d.	58	n.d.	71
St. John				
50 mm Sand	71	62	75	72
50 mm Soil	72	55	70	75
150 mm Sand	n.d.	55	n.d.	71
150 mm Soil	n.d.	58	n.d.	72
Kakanui				
50 mm Sand	77	58	64	71
50 mm Soil	73	53	64	65
150 mm Sand	76	57	75	65
150 mm Soil	n.d.	46	n.d.	65

[1] Mean values

APPENDIX 6.16 A subjective assessment of grass cover and soil cracking durin the first preparation of 1986/87.

Pitch Soil, Depth, Base Material	Cracking			Cover		
	Day 5	Day 12	Day 23	Day 5	Day 12	Day 23
Palmerston North						
50 mm Sand	1-2	2	2	1	1	1
50 mm Soil	1-2	1-2	1-2	1	1	1
150 mm Sand	1-2	1-2	1-2	1	1	1
150 mm Soil	1-2	1-2	1-2	1-2	1-2	1-2
Ward						
50 mm Sand	4	4	5a,b	1	1	1
50 mm Soil	4	4	5a	1	1-2	1-2
150 mm Sand	4	4	4	1	1-2	1-2
150 mm Soil	4	4	4a	2	3	3
St. John						
50 mm Sand	2	2-3	2-3	1	1-2	1
50 mm Soil	2-3	2-3	2-3	1-2	1-2	1-2
150 mm Sand	3	3	3	1	1	1
150 mm Soil	2-3	3	3	1-2	2-3	2-3
Kakanui						
50 mm Sand	3-4	4	5	1	1-2	1-2
50 mm Soil	3-4	3-4	4	3	3-4	3
150 mm Sand	3	3-4	4b	1-2	1-2	1-2
150 mm Soil	3	3	4	3	2-3	3

[a] Crumbling at Crack Edges

[b] Blocks between cracks unstable

Key

	Cracking		Cover
1	minimal	1	Poor
2	minor-moderate	2	Average
3	extensive	3	Good
4	excessive	4	Very good

APPENDIX 6.17 A subjective assessment of grass cover and soil cracking during the second preparation of 1986/87.

Pitch Soil, Depth, Base Material	Cracking			Cover	
	Day 19	Day 24	Day 26	Day 19	Day 24
Palmerston North					
50 mm Sand	1	1	1	1	1-2
50 mm Soil	1	1	1	2-3	3
150 mm Sand	1	1	1	1-2	1-2
150 mm Soil	1	1	1	1-2	1-2
Ward					
50 mm Sand	2	3-4	4-5[a,b]	1-2	1-2
50 mm Soil	3	3-4	4-5[b]	2-3	2-3
150 mm Sand	3	3	4	2	2-3
150 mm Soil	2-3	4	4	1-2	2
St. John					
50 mm Sand	2-3	2-3	3-4[a]	1-2	1-2
50 mm Soil	1-2	2-3	3-4[a]	1-2	2-3
150 mm Sand	2-3	2-3	3	1-2	1-2
150 mm Soil	1-2	2	3	1-2	2
Kakanui					
50 mm Sand	3	3	5[a,b]	1	2-3
50 mm Soil	3	3	4[b]	3	3
150 mm Sand	3	3	4-5[b]	2	3
150 mm Soil	2	3	3-5[b]	1-2	2-3

[a] Crumbling at Crack Edges

[b] Blocks between cracks unstable

Key

Cracking	Cover
1 minimal	1 Poor
2 minor-moderate	2 Average
3 extensive	3 Good
4 excessive	4 Very good

APPENDIX 6.18 A subjective assessment of grass cover and soil cracking during the second preparation of 1987/88.

Pitch Soil, Depth, Base Material	Cracking			Cover	
	Day 9	Day 20	Day 44	Day 9	Day 44
Palmerston North					
50 mm Sand	1	1	1	1-2	1-2
50 mm Soil	1	1	1	1-2	1-2
150 mm Sand	1	1	1	1-2	1-2
150 mm Soil	1	1	1	2-3	2-3
Ward					
50 mm Sand	2-3	2-3	4	3	3
50 mm Soil	3-4	3-4	3-4	1-2	1-2
150 mm Sand	3-4	3-4	3-4	2-3	2-3
150 mm Soil	3-4	3-4	3-4	2-3	2-3
St. John					
50 mm Sand	2-3	2-3	2-3	1	1
50 mm Soil	2	1-2	2	2	1-2
150 mm Sand	2	2	2	1	1
150 mm Soil	3	2-3	2-3	1	1
Kakanui					
50 mm Sand	3-4	3-4	4	2-3	2-3
50 mm Soil	3	3-4	3-4	1-2	1-2
150 mm Sand	4	4-5	4-5	1	1
150 mm Soil	3-4	4-5	4-5	1-2	1-2

[a] Crumbling at Crack Edges

[b] Blocks between cracks unstable

Key

Cracking		Cover	
1	minimal	1	Poor
2	minor-moderate	2	Average
3	extensive	3	Good
4	excessive	4	Very good

APPENDIX 6.19 Changes in trial plot infiltration rates (mm hr^{-1}) over time on Day 5 of the first preparation of 1986/87.

	Time (mins)			
Trial soil depth - base combination	0-2	5-10	30-45	60-75
Palmerston North				
50 mm over sand	8	2.3	1.0	1.0
50 mm over soil	28	9	3.7	0.9
150 mm over sand	20	3.0	2.2	1.2
150 mm over soil	9	1.8	1.2	1.0
Ward				
50 mm over sand	850	300	200	50
50 mm over soil	90	20	20	18
150 mm over sand	300	300	160	30
150 mm over soil	800	550	320	300
St. Johns				
50 mm over sand	1000	110	30	10
50 mm over soil	440	75	30	11
150 mm over sand	76	15	14	-
150 mm over soil	82	15	9	2
Kakanui				
50 mm over sand	170	120	60	2
50 mm over soil	30	15	7	5
150 mm over sand	160	90	50	25
150 mm over soil	45	20	15	2

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