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PROJECT REPORT

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Soils of Lakeland Downs

M. J. Grundy and I. J. Heiner
Land Use and Fisheries

DPI QUEENSLAND
DEPARTMENT OF PRIMARY INDUSTRIES

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Department of Primary Industries
GPO Box 46
Brisbane Q 4001

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Abstract

The soils of the basalt landforms of Lakeland Downs in far north Queensland (15.9°S, 144.9°N) are described in terms of their morphology, soil chemical and physical attributes and their location. Lakeland Downs is an increasingly important area of rainfed and irrigated agriculture and this report is the first inventory of the soils of the area.

The most common soils are deep red friable soils with moderate fertility and high water holding capacity. These are named Blackburn and Laura in the study (Australian soil classification - red Ferrosol; Euchrozem in Great Soil Group terminology). These soils have minor limitations to irrigated agriculture or rainfed agriculture (provided adequate rainfall is received). Other soils which are suitable for a wide range of agricultural uses include the moderately deep brown and yellow soils, Maclean and Bullhead. These have a higher degree of seasonal wetness (Australian soil classification - brown Ferrosol and brown Dermosol; Euchrozem and Xanthozem in Great Soil Group terminology). Normanby, a black or grey cracking clay soil, is suitable for grain crops where there is a sufficiently large area of the soil (Australian soil classification - black or grey Vertosol; Black Earth or Grey Clay in Great Soil Group terminology). Other soils include Bubbler, a shallow soil with significant erosion and moisture capacity limitations, and Lily, a poorly drained soil with low levels of plant nutrients.

Most of the soils are not easily identified from an examination of the surface and can not be reliably predicted from the position in the landscape. Consequently, a key is provided to aid identification from small holes or exposures.

The report is accompanied by a map of broad land resource areas. A site database of some 74 sites, seven with detailed chemical and physical data was produced during the survey and is available on request.

1. Introduction

This publication forms the technical report of a resource assessment of the Lakeland Downs area in far north Queensland. The work was commissioned by the Land Conservation Branch of the Queensland Department of Primary Industries (QDPI) and performed by officers of the then Land Resources Branch, QDPI. The work was designed to document the soil and land resources of the basalt lands around the township of Lakeland Downs. This area has become an increasingly important area of rainfed and irrigated agriculture. Little was known of the soil resources on which this development was based. This technical report is supplemented by a map of the broad land resource areas and a key for soil identification.

1.1 Location and land use history

Lakeland Downs is a small agricultural region of some 10,000ha centred around the basaltic areas of the Maclean Province, some 200 km north-west of Cairns (15.9°S, 144.9°N; Figure 1). The volcanic eruptions which formed the lava plains on which the region is based occurred in the late Tertiary resulting in olivine basalts and pyroclasts. The soils on the basalt province are predominantly Euchrozems (or Ferrosols under the new Australian Classification) of varying depth, although a range of other basaltic soils occur. The surrounding land is hilly or mountainous formed from sedimentary and granitic rocks with only limited arable soils.

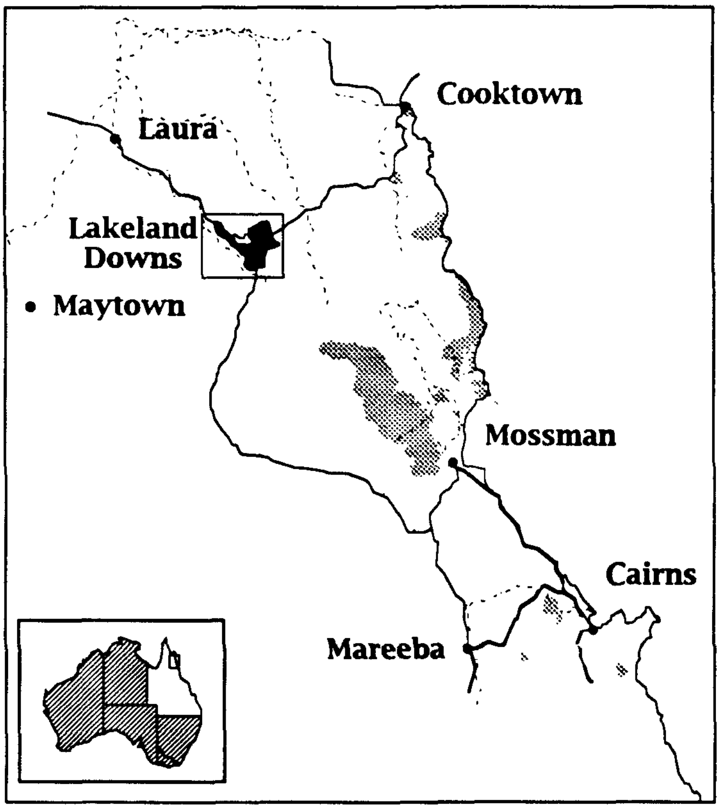

Figure 1 Location of the study area (lines roads; dashed lines - rivers; hached areas - national parks and reserves)

Prior to the late 1960s, the area had a reputation as highly productive cattle country. At that time, it was purchased by Mr Clive Foyster and an ambitious development program commenced. Some 10,000ha were cleared and dams constructed with the aim of irrigated sorghum production for export. The scheme was ultimately unsuccessful but a large area of arable land had been cleared and made available for agriculture. After some years of unsuccessful cultivation, advances in cultural techniques allowed the successful cropping of a maize-peanut rotation. Yield from the area has steadily increased to the point where the 1988 harvest resulted in approximately 3,500 tonnes of peanuts (compared with the Atherton Tableland production of 10,000 tonnes).

Despite this history and its current significance in north Queensland agriculture, there has been no detailed soils appraisal of the area, apart from some surface soil sampling for nutritional status, and there are no data on potential erosion or salinity hazards. The range of crops grown is likely to increase and information is required on the range of soils present and their suitability for various uses. The presence of substantial dams has meant that irrigation is now feasible in some areas. The largest landholder has established a coffee plantation.

1.2 Land use issues

The area has potential for significant land degradation. The QDPI strategy for degradation minimisation uses a community development approach through property management planning. This requires maps and descriptions of land resources as background and source information.

Soil erosion is the major potential form of land degradation. Much of the area is on long slopes of 3-4% with summer dominant and intense rainfall. Experience elsewhere in Queensland has also indicated a tendency for basaltic soils with a similar range of crops to become severely compacted.

The potential for soil erosion arises from the intensity of early summer rainfall on bare or substantially uncovered soil and from the long slopes typical of most of the landforms. Good surface soil structure is maintained under natural vegetation. Increased exposure of the soil to sunlight and rainfall, physical disruption by soil tillage and the removal of soil organic matter through crop harvesting cause physical decline through the reduction and destruction of soil organic matter and direct physical force. Soil compaction will arise from the use of heavy machinery on wet soils during cultural and harvesting operations. The inherent characteristics of the soils impact on the potential for all forms of degradation.

1.3 Resource assessment at Lakeland Downs

QDPI plans to proceed in two stages with resource assessment of Lakeland Downs. This report documents the results of the first stage; the second stage awaits a funding allocation or external funding. The first stage aimed at surveying the land and soil resources with sufficient intensity to identify the major soil types and their attributes and place them in a landscape context. The second is designed to establish a detailed land suitability schema based on primary data and decision rules and to map the occurrence of soils at a scale relevant to properties.

2. Geology, Landform and Climate

2.1 Geology and landform

The basaltic landscape of Lakeland Downs results from the laval outpourings of the volcanoes of the Maclean Province over the steeply-folded Upper Palaeozoic Hodgkinson formation and the alluvia of the Laura and Normanby Rivers (Stephenson et al. 1980). Small areas of basalt occur in discrete areas outside the major eruption centres near the township of Lakeland Downs but these were not included in the study. The eruptions appear to have occurred over the period 4 million to 0.5 million BP and the extruded lavas were dominated by nephelinite and alkali basalt.

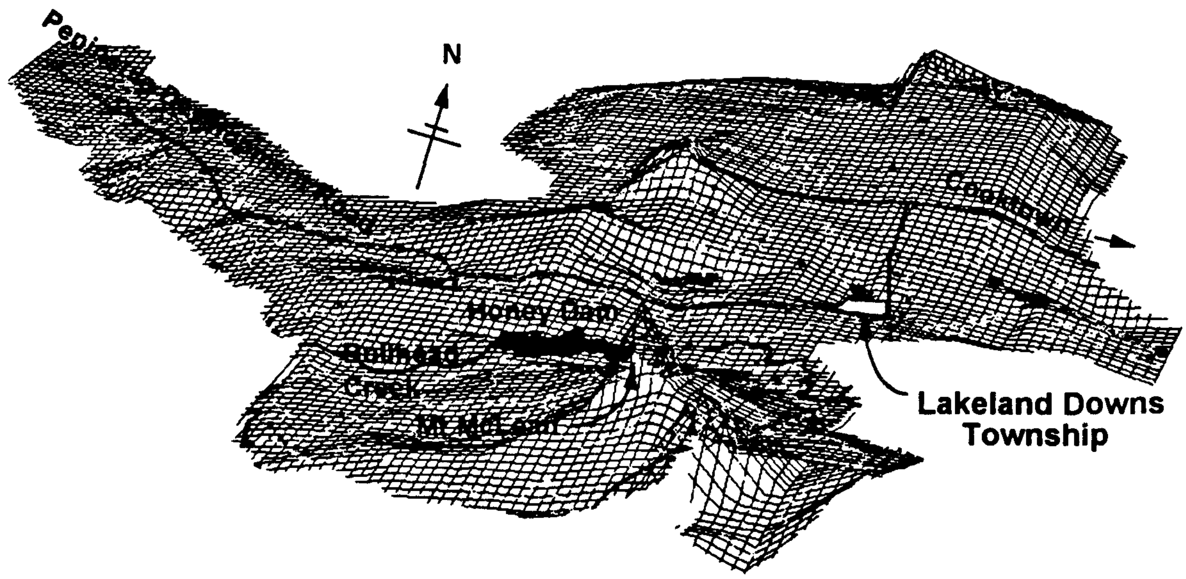

Figure 2 Three dimensional representation of the landform of Lakeland Downs viewed from the south-southeast (the black dots are field description sites)

The landform ranges from level to gently sloping plains (slope 0-4%) with emerging volcano remnants (Figure 2). To the west where lava has filled the old valley of the Laura River, a low extended mesa has developed with a level surface and dissected sides. There is a marked contrast with the surrounding steep slopes of the Hodgkinson sediments.

2.2 Climate and water resources

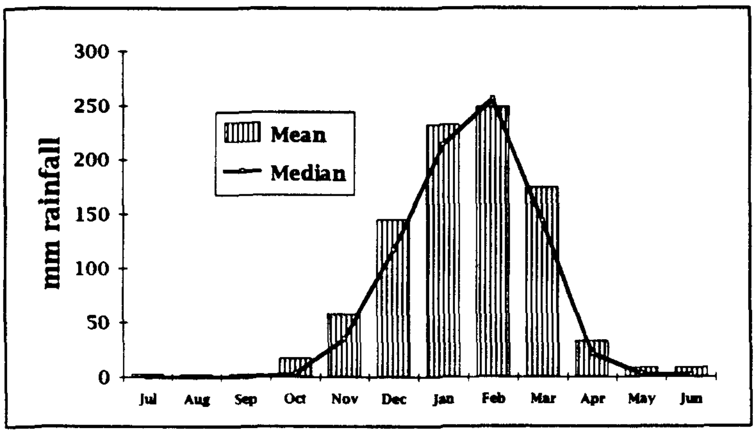

Figure 3 Mean and median monthly rainfall at Laura

Lakeland Downs is a relatively elevated lava plain (300m) some 70 km from the coast. The influence of the southeast trades is substantially modified by coastal ranges so that the most significant rainfall influence in the area is the northwest summer monsoon. Rainfall is recorded at two sites within the Lakeland Downs area but both have a small sample of years. A much longer record is available for Laura some 50km to the west and some 200 m lower in altitude and these data are used in this discussion. It is probable that the study area receives higher rainfall than Laura although the difference is unlikely to be large.

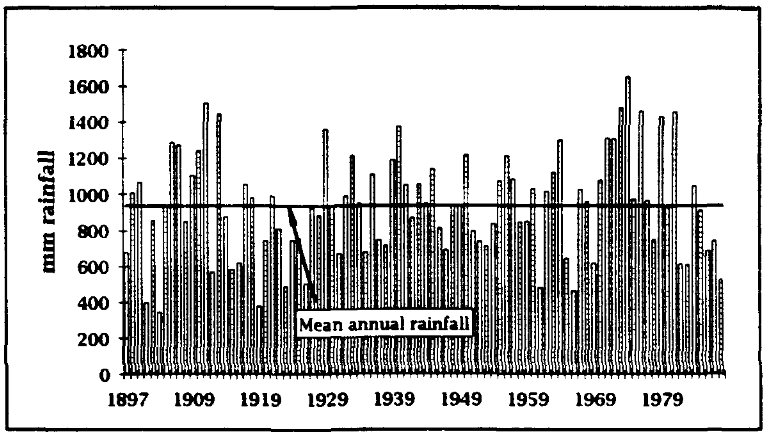

Figure 4 Annual rainfall at Laura. Where there were gaps in the record (3 years), the average rainfall has been substituted

Laura has an average annual rainfall of some 936mm with a pronounced summer dominance (Figure 3). Almost no rainfall is recorded in most years in the months from May to September. Median values closely mirror the mean suggesting that there are as many above average as below average years.

There is substantial year to year variability (Figure 4). In the driest of years, annual rainfall is about 400-500mm; the wettest years produce annual falls of greater than 1400mm. There has been a pattern of variation over the 90 years of record with relatively wetter periods being experienced in the early 1900s, 1940s and most notably in the 1970s when much of the development for cropping occurred. Clearly, average statistics, probability analysis based on the whole record, or even personal experience will inadequately predict short to medium term rainfall prospects.

No temperature or evaporation data are available for the area. Calculated data for the nearby site of Maytown (Figure 5) suggest that maximum temperatures peak in November at an average value of approximately 36^{o} and are lowest in July (14^{o}). The area experiences no frosts.

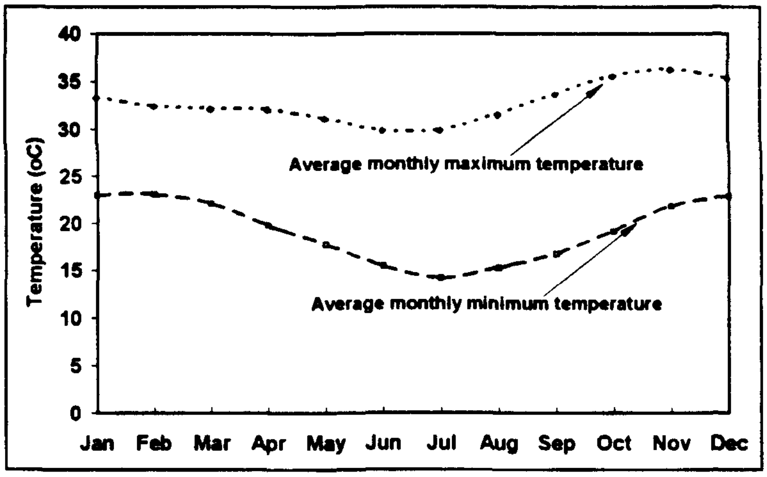

Figure 5 Calculated temperature data for the town of Maytown (source: DPI Climate Data Bank)

Tropical cyclones occur sporadically and unpredictably. Those which come close to the area bring destructive wind gusts which threaten buildings and crops. Otherwise, cyclones in the area are an important source of significant rain. Thunderstorms with hail can occur in the October to December period.

3. Methodology and Nomenclature

3.1 Methods used

Soil variability in the study area was determined by selectively traversing soil, landform and vegetation patterns which were identified using air photos at a scale of approximately 1:25,000. Soils were described in detail at 0.6 to one km intervals or where a soil change occurred. The data collected included morphological details of the soil at the site as well as attributes of the surrounding landscape using the procedures and codes of McDonald *et al.* (1984). A total of 74 sites were described and entered on computer files. The major groupings of soils (or Soil Profile Classes) were collated and named. A soil key was then prepared. At seven sites which were identified as being typical of each of the named soils, a 15 cm undisturbed core to a depth of 1.5m or the depth of soil was collected. These cores were described in detail and sampled for chemical analysis. The methods employed are detailed in Section 5.1 and the descriptions and chemical analyses are shown in Appendix 2.

The soil site data were used with air photo interpretation to map the area into broad groupings of soils and landform. These land resource areas were then mapped into a geographic information system (GIS) file. A print of this map is attached to this report. Additional information will be prepared as QDPI Ref Notes to briefly highlight aspects of the work in a form useful to field officers and farmers.

3.2 Terms used in the report

A number of codes and defined terms are used in this report to identify soil types or as a short hand for concepts and/or procedures used in discussing the results. These are described here to assist in using the included information.

- **Soil profile class:** named classes of soils with explicit ranges of soil attributes. They are derived by grouping soil morphological data into recurring classes ie. they are a soil classification derived from the land not imposed on it.
- **Soil or Soil type:** Synonyms for soil profile class
- **Land resource area (LRA):** recurring combinations of landform and soils. In the Lakeland Downs study, LRA are the broad groupings on the map attached to the report. They assist in the first stage of identifying soils.
- **Land suitability class (LSC):** One of five defined classes of land based on the limitations inherent in the land for a particular purpose. The five classes are defined in Appendix 3.
- **Land limitation class:** These are ratings from one to five defined as for the LSC and used to assess the effect on suitability of one of the possible limitations inherent in land. Sub-classes for a number of limitations are grouped for each crop and/or land use to arrive at the LSC.
- **Cation Exchange Capacity (CEC):** A measurement of the ability of the soil to hold and exchange cations. Most soil surfaces are negative and attract positive ions such as calcium, magnesium, potassium and sodium thus preventing leaching from the soil. The attracted ions are exchangeable and consequently available to plants.

- **Soil horizons:** A term used to describe the layering observed in soils. In all Lakeland Downs soils, the A horizon is the surface layer in which organic matter accumulates. The B horizon is the layer below the A horizon in which colour and/or clay content tend to be at a maximum. C horizon is used to describe the weathering material in which the soil is forming. Some soils are underlain by materials which differ from the overlying soils; these are referred to as D horizons. All horizons can be subdivided a number of times and this is indicated with a numeric suffix, for example A2 or B2.

4. Land Resource Areas and Soil Profile Classes

4.1 Land resource areas - names and concepts

This study was not primarily a mapping exercise. It was possible to identify from the traverses, however, a broad grouping of soil classes based on landform position and soil variability. The accompanying map delineates some seven land resource areas (LRA) which are recurring combinations of landform and soils. The content of these LRA is detailed in Table 1. The attributes of the named soils are described in Section 4.2 and, in more detail, in Appendix 1.

Table 1 Land Resource Areas of Lakeland Downs

Land Resource Area	Landform	Principal soils	Associated soils	Great Soil Groups*	Principal Profile Forms**	Area (ha)
1	Level, narrow basalt plateaus; some areas with abundant rocks; bounded by rocky scarps	Laura	Blackburn	Euchrozem	Uf 6.31 Gn 3.12	608
2	As above, but with gilgai	Bullhead Normanby	Maclean Laura	No suitable group affinities with Xanthozem, Black Earth	Uf 6.34 Uf 6.31 Gn 3.22 Ug 5.12	789
3	Very gently undulating basalt lava plains; isolated areas with few rocks	Lily Blackburn	Maclean	No suitable group affinities with Yellow Earth, Euchrozem	Gn 2.22 Uf 6.71 Uf 6.31	1,620
4	Very gently undulating basalt lava plains	Blackburn Laura	Bullhead Maclean	Euchrozem	Uf 6.31 Gn 3.12	4,164
5	Level to very gently undulating basalt lava plains; isolated areas with few rocks	Normanby		Black earth/Grey Clay	Ug 5.12 Ug 5.13 Ug 5.26	403
6	Very gently to gently undulating basalt lava plains; some areas with abundant rocks	Bubbler	Bullhead	No suitable group affinities with (shallow) Prairie Soil	Uf 6.53 Uf 6.71	151
7	Gently undulating basalt lava plains; isolated areas with few rocks	Bullhead	Maclean Blackburn	No suitable group affinities with Xanthozem	Uf 6.34 Uf 6.31 Gn 3.22	294

* Stace *et al.* (1968) ** Northcote (1979)

4.2 Soil profile classes

Soil Profile Classes are named classes of soils with explicit ranges of soil attributes. They are derived by grouping soil morphological data into recurring classes. At Lakeland Downs, seven soils were identified based on 74 field descriptions of soil profiles. These soils encompass almost all the variation observed in the soils at Lakeland Downs to this stage. More detailed survey may identify important soil profiles which lie outside these ranges of attributes but the number is unlikely to be large.

Blackburn and Laura

The Blackburn and Laura soils include the deep, structured red soils of the area. Typically, both soils have dark or red light clay A horizons to 15 cm (range 12 to 19 cm) although most sites had been ploughed to 25-30 cm. These grade through a red, light to light medium clay B1 horizon to the B2 horizon which typically starts at around 30-40 cm. The B2 horizon is red, moderately or strongly structured, usually extends to at least 1.5m and decreases slightly in texture from light medium or medium clay to light clay at depth. The C horizon, where it occurs, is deeply weathered basalt. Field pH increases with depth from acid in the surface (6.0) to neutral at depth (6.5-7.0). Neither soil is mottled. The major difference between Laura and Blackburn is that the Laura soil has significant ironstone nodules in the subsoil which increase with depth. This may indicate that Laura is less freely drained than Blackburn, but the difference is likely to be minor as both are well drained soils. The difference may be important in the development of soil compaction, but more quantitative measurements and/or experience is required.

Maclean

This is a deep red-brown to brown structured soil. The A horizon is dark or red, clay loam or light clay, about 20 cm deep and is moderately structured. It grades through a brown or red-brown B1 horizon (where present) to a moderately to strongly structured red-brown to brown B2 horizon to 1.3m or more. The B2 horizon ranges from light clay to medium clay and has small quantities of fine ferromanganiferous nodules and some fine red and yellow mottling. The pH ranges from slightly acid in the surface to neutral at depth. A weathered basalt layer underlies the soil at depth.

Bullhead

Bullhead is a deep, brown to yellow soil with increasing mottles and nodules with depth. The A horizon is dark or brown light clay or clay loam with weak to moderate structure extending to about 15 cm when not ploughed (range 11 to 22 cm). It grades through a brown or red-brown B1 horizon (where present) to a weakly to strongly structured brown to yellow B2 horizon to 1.5m or more. The B2 horizon ranges from light clay to light medium clay and has ferromanganiferous nodules and yellow and red mottling increasing appreciably with depth. The pH ranges from slightly acid in the surface to neutral at depth. Under some soils, a medium to medium-heavy clay, yellow-grey D horizon was observed with strong polyhedral structure and red mottling. A weathered basalt layer underlies the soil at depth.

Bubbler

Bubbler is a shallow soil grading into weathering basalt before 70 cm. The A horizon is dark or brown light medium clay grading to a weakly structured, red or red-brown, light clay B horizon which is in turn underlain by weathering basalt by about 60 cm. Nodules and basalt gravel are common throughout the profile. The pH ranges from slightly acid in the surface to neutral at depth.

Normanby

Normanby is a cracking clay soil found on level plains in the east of the area. The A horizon is dark , medium to medium heavy clay, about 15 cm deep and is moderately to strongly structured. It grades to a moderately to strongly structured dark B2 horizon to 1.3m or more. The B2 horizon ranges from medium to heavy clay and has small quantities of fine ferromanganiferous nodules and may have carbonate nodules which increase with depth. The pH ranges from slightly acid in the surface to alkaline at depth. A weathered basalt layer underlies the soil at depth.

Lily

Lily is a deep yellow or brown soil. The A horizon is dark or brown, clay loam or light clay, about 10 cm deep (where unploughed) and is weakly to moderately structured. It changes abruptly to a massive yellow or brown upper B2 horizon which changes to moderately or strongly structured darker layers by 60-80 cm. The upper B2 horizon is predominantly clay loam while the deeper layers range from light clay to medium clay. There are fine to medium manganiferous and ferromanganiferous nodules throughout, while red mottling is common in the deeper layers. The pH ranges from slightly acid in the surface to neutral at depth.

4.3 Soil key

To aid the identification of soils in the field, a soil key was devised based on readily identified soil characteristics (Table 2). A user would need to observe the colour of the surface and subsurface soil and be able to identify ironstone nodules, mottles and the presence of decomposing rock. With these relatively simple observations, it would then be possible to relate the described soil to the wealth of soil morphological and analytical data collected as part of this study.

Table 2 Key to the soils of Lakeland Downs

LAKELAND DOWNS SOIL KEY			
1. a	Soil has a dark or very dark grey surface covered in loose soil crumbs. Soil cracks when dry.		**NORMANBY**
b	Soil does not crack.	*Go to 2*	
2. a	Soil subsurface layers are red.	*Go to 6*	
b	Soil subsurface layers are yellow to brown.	*Go to 3*	

LAKELAND DOWNS SOIL KEY				
3.	**a**	A distinctive yellow massive layer occurs below a brown surface.		**LILY**
	b	Soil subsurface layers are brown.	*Go to 4*	
4.	**a**	Soil grades into mottled decomposing basalt before 70 cm.		**BUBBLER**
	b	Soil is deeper than 70 cm	*Go to 5*	
5.	**a**	Soil subsurface layers are brown to yellowish brown with mottles and ironstone nodules increasing with depth.		**BULLHEAD**
	b	Subsurface layers are brown with very few if any mottles or nodules.		**MACLEAN**
6.	**a**	Subsoil layers have ironstone nodules increasing with depth.		**LAURA**
	b	Subsoil layers are deep with very few, if any, ironstone nodules.		**BLACKBURN**

4.4 Hypotheses of soil formation

The morphological observations and the analytical data derived for representative soils (Section 5) led to the following hypothesis of soil development. Blackburn, Laura, Maclean and Bullhead are moderately deep to deep clay soils formed on basalt or in basalt colluvium. They fall on a continuum in drainage status from well drained to poorly drained, corresponding to an increase in illitic or 2:1 lattice clays relative to the less reactive kaolinitic clays. The development of these clay types and these drainage conditions has presumably been driven by landscape position and perhaps by variation in parent material. Normanby is a soil dominated by swelling montmorillinitic clays which has formed on basalt in landscape positions where water was unable to leach through the developing soil. Bubbler is a shallow soil on basalt slopes where erosional processes have restricted soil development. Lily is most difficult to fit into this scenario. Morphologically and chemically it appears quite different to the other soils as though it has formed in non-basaltic colluvia which has washed over weathering basalt

5. Soil attributes

5.1 Soil chemistry

Soil chemistry of Lakeland Downs soils was investigated by sampling seven profiles chosen to represent the soils defined from the field study. The methods follow those listed in Baker and Eldershaw (1993) except as detailed in the discussion. Only one profile is available for each soil and the extent to which the analysis is representative of the members of the soil profile class is dependent on how each chemical attribute covaries with the morphological attributes which were used in the grouping. This covariance is more likely to be a reasonable hypothesis in the situation where the soils have formed from similar parent materials, but which differ due to variations in the environment in which soil genesis occurred. Such a situation applies to the Lakeland Downs soils (with the possible exception of Lily). The soil chemistry data are explicable in terms of the various soil morphological attributes used to group them, and in the likely modes of pedogenesis.

Soil fertility analyses were performed on surface soil samples (nine samples were collected from each site and bulked before analysis). Aspects of these data are difficult to interpret due to the degree of disturbance associated with current or past cropping. All sampled soils with the exception of Normanby and the possible exception of Maclean had been cultivated and cropped and there had been disturbance of the top 20 to 30 cm of soil. In addition, there are no data on fertiliser additions on any of the sampled soils.

Cation exchange capacity (CEC)

Blackburn This well drained soil has a relatively low level of CEC throughout the profile with a concentration in the more organic A horizon (Figure 6). Calcium dominates the exchange complex decreasing slightly with depth accompanied by a slight increase in exchangeable magnesium (Figure 9). There is no appreciable exchangeable sodium in any horizon.

Laura This soil is similar morphologically to Blackburn and its cation chemistry is almost identical (Figure 7). The sampled profile differs slightly in that calcium increases down the profile but the difference is minor and could not be inferred to be a general difference. The highest level of CEC is again

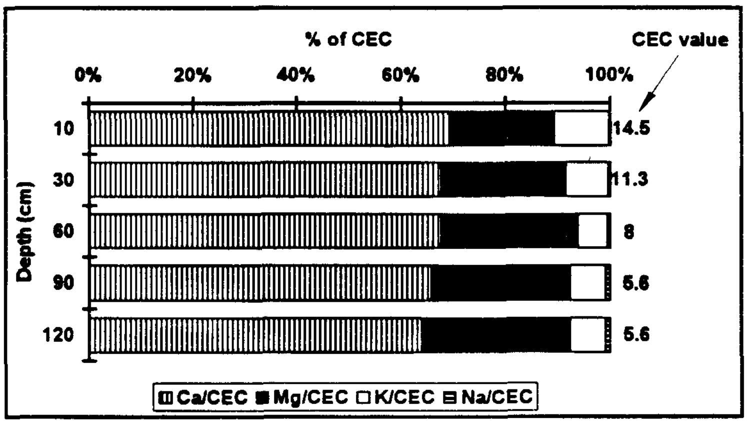

Figure 6 Cation exchange capacity of the Blackburn soil of Lakeland Downs

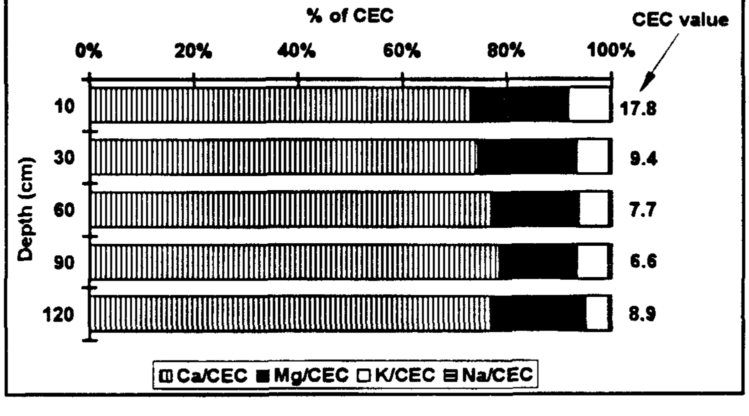

Figure 7 Cation exchange capacity of the Laura soil of Lakeland Downs

concentrated in the surface with the organic matter (17.8 meq/100g compared with 9.4 at 30 cm). The loss of small amounts of this organic rich material through erosion would clearly impact significantly on the overall soil nutrient availability.

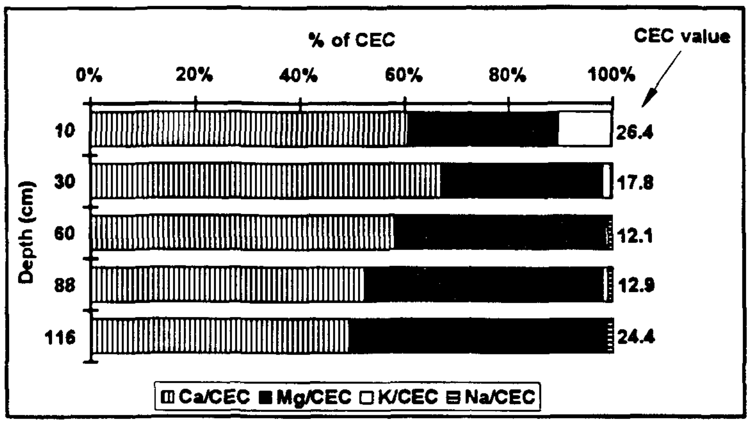

Figure 8 Cation exchange capacity of the Maclean soil of Lakeland Downs

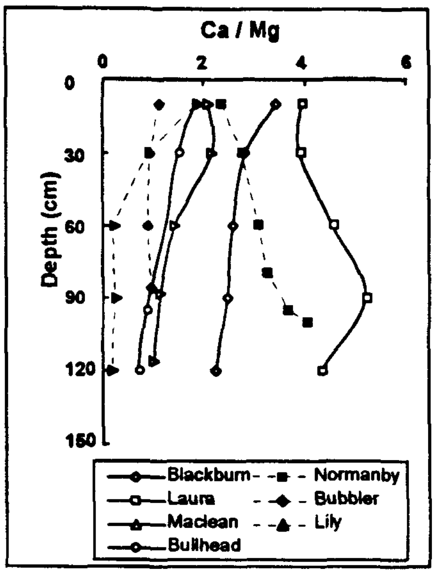

Figure 9 The ratio of exchangeable calcium to exchangeable magnesium in Lakeland Downs soils

Maclean Maclean differs only in soil colour from Laura but this colour difference is indicative of a significant difference in cation chemistry (Figure 8). CEC is highest in the surface as in the red soils, Blackburn and Laura (associated with soil organic matter), but the level in all horizons is appreciably higher than in Blackburn and Laura and there is an increase with depth. In addition, the calcium-magnesium ratio decreases markedly down the profile (Figure 9). Significant levels of potassium in the soil exchange are confined to the surface. There is no appreciable sodium throughout the profile.

Bullhead Bullhead is the most poorly drained of the sequence comprising Blackburn, Laura, Maclean and Bullhead. In this soil, the CEC level is higher throughout most of the profile (Figure 10) and the decrease in calcium is more marked than in the other soils. This decrease is accompanied by an increase in both magnesium and sodium. As in the Maclean soil, potassium is concentrated in the surface soil and virtually disappears from the exchange below 10cm.

Normanby This cracking clay soil is markedly different morphologically from the other soils

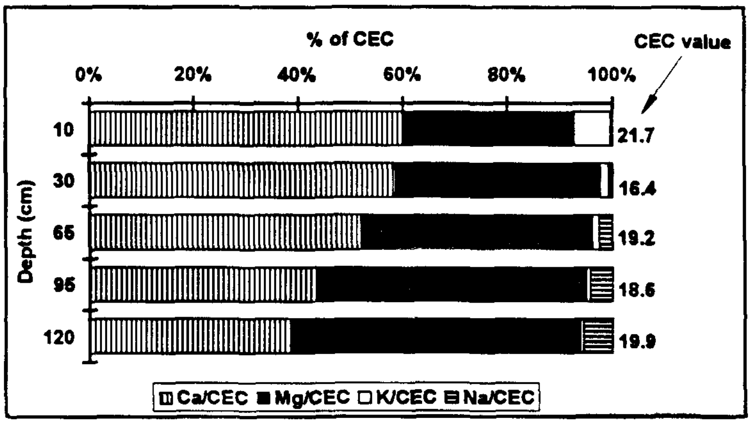

Figure 10 Cation exchange capacity of the Bullhead soil of Lakeland Downs

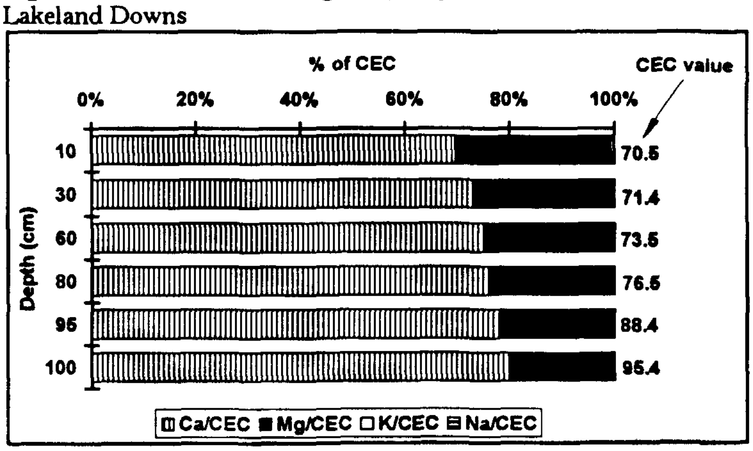

Figure 11 Cation exchange capacity of the Normanby soil of Lakeland Downs

in the area and this difference is reflected in the soil chemistry (Figure 11). The CEC levels greatly exceed those found in all other soils reflecting the dominance of montmorillonite in the clay mineralogy. Calcium is the dominant cation. Potassium is present in small proportions in the surface and magnesium decreases with depth. There is no appreciable sodium.

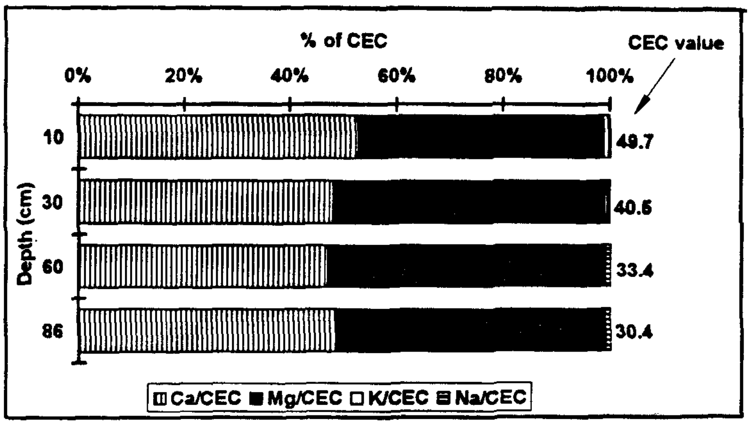

Figure 12 Cation exchange capacity of the Bubbler soil of Lakeland Downs

Bubbler This is a relatively shallow soil with characteristics suggestive of a youthful stage of pedogenesis (Figure 12). The CEC levels are relatively high suggesting a dominance of illitic clay minerals. Calcium and magnesium are the dominant cations with relatively small quantities of both potassium and sodium.

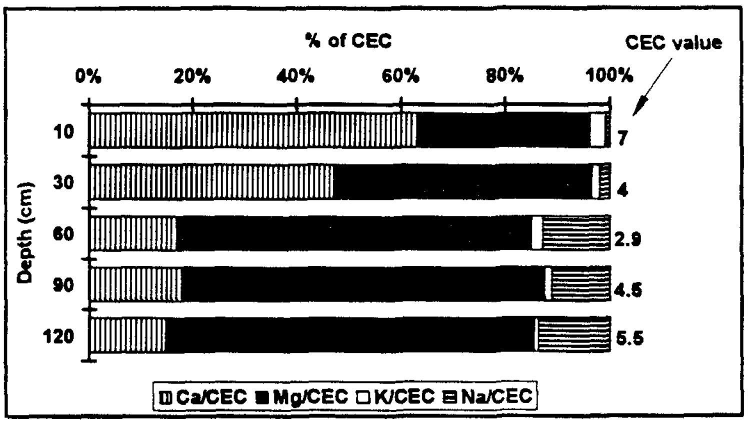

Figure 13 Cation exchange capacity of the Lily soil of Lakeland Downs

Lily Lily differs markedly from all other sampled soils both morphologically and in its chemical attributes (Figure 13). The level of CEC is low through the whole profile relative to all other soils sampled. There is also a marked difference between the surface depths and most of the B horizon. Calcium changes from being the dominant cation (to 30cm) to being small in proportion to magnesium. Sodium proportions are also high in the bottom half of the profile reinforcing the observed slow permeability of these soils and their consequent susceptibility to waterlogging. Absolute levels of all cations are low, however, and cation proportions are less reliable in predicting soil behaviour in such cases.

pH

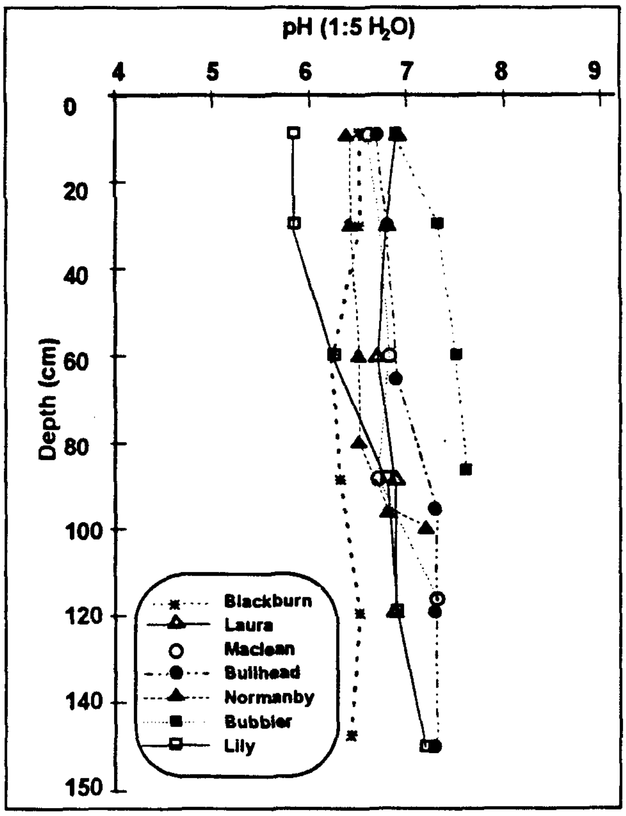

Figure 14 pH trends down the profile of Lakeland Downs soils

Most soils sampled at Lakeland Downs fell into the range from pH 6 to pH 7 (Figure 14). The notable exceptions were Lily, which is acid in the surface becoming neutral with depth, Bubbler which exceeds 7 in all but the surface layers and Normanby which becomes alkaline with depth. The change in the Lily soil is associated with the increase in sodium on the exchange complex. The Bubbler soil (relatively young in terms of soil development) probably more closely reflects the pH of the parent material, and the increase in pH in the Normanby soil is associated with the occurrence of carbonate segregations at depth and increasing calcium dominance of the soil exchange complex. Field pH data for Normanby soils suggest that lower layers exceed pH 8.

Organic carbon and nitrogen

Relatively high levels of both organic carbon (Figure 15) and total nitrogen (Figure 16) were found in the Normanby soil which appears never to have been cropped and the Maclean soil which although cleared may not have been cropped. The Maclean soil was covered in dense grass. The Laura soil had a relatively high level of organic carbon.

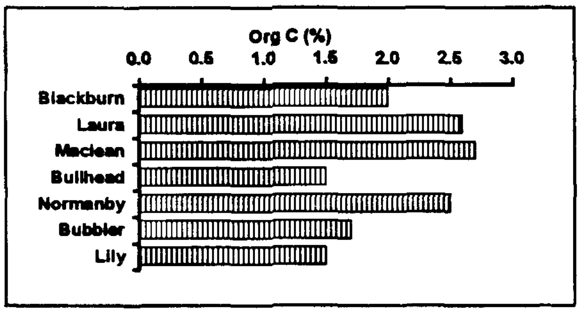

Figure 15 Organic carbon for the seven soils identified in the Lakeland Downs area

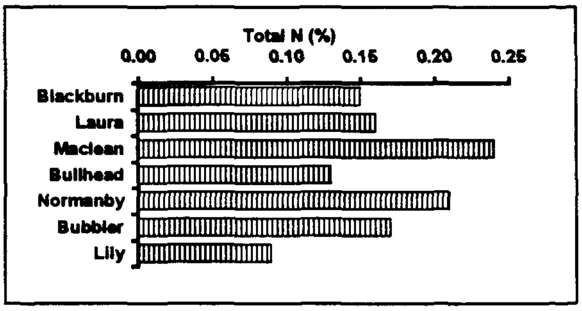

Figure 16 Total nitrogen for the seven soils identified in the Lakeland Downs area

All levels are low by international standards and relatively low by Australian standards. Given the concern of the usefulness of the absolute figures, the ratio of carbon to nitrogen is often a useful indicator of the ability of the soil to supply nutrients from the organic matter pool. All soils have relatively low ratios (Figure 17) which suggests that mineral N will be readily released from organic sources (Raymont and Higginson 1992, p58).

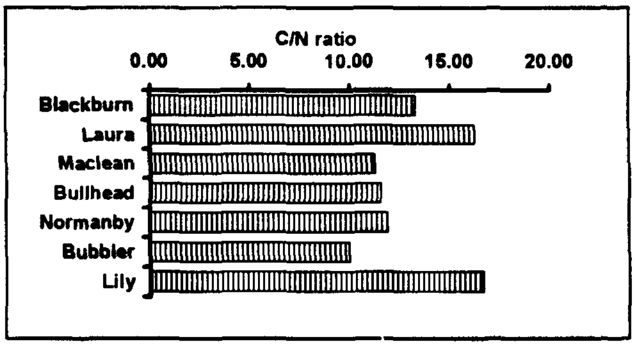

Figure 17 Carbon - nitrogen ratio for the seven soils identified in the Lakeland Downs area

Phosphorus and potassium

The levels of phosphorus measured in the soil surface samples reflected both the cropping and cultivation history and, in the case of Lily, the parent material (Figure 18). High levels of bicarbonate extractable phosphorus were measured in the Normanby and Maclean soils both of which are relatively undisturbed. Levels were still moderate to high in the remaining basalt soils and low in the Lily soil which would require fertilisation for crop growth.

Extractable K levels were high in terms of plant or crop needs and variable without a discernible pattern (Figure 19). The levels of both of these major nutrients were markedly lower in the Lily soil supporting the hypothesis that at least the surface layers of this soil are derived from non-basaltic parent materials. The Lily soil would require fertilisation for adequate crop growth.

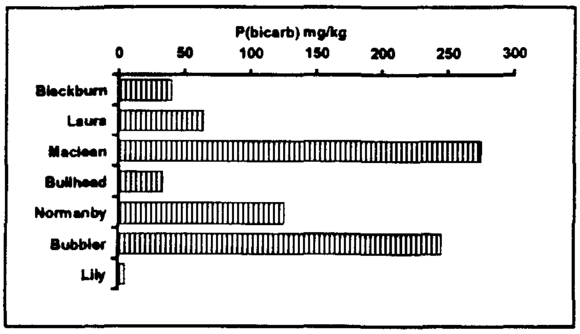

Figure 18 Bicarbonate extractable phosphorus in the seven soils defined for the Lakeland Downs area

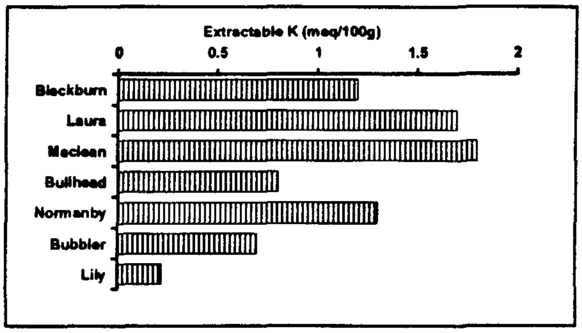

Figure 19 Extractable potassium in the seven soils defined for the Lakeland Downs area

Iron, manganese, copper and zinc

There are no clear patterns in the iron contents of the Lakeland Downs soils. All iron values are relatively high in terms of plant requirements but appreciably higher values were

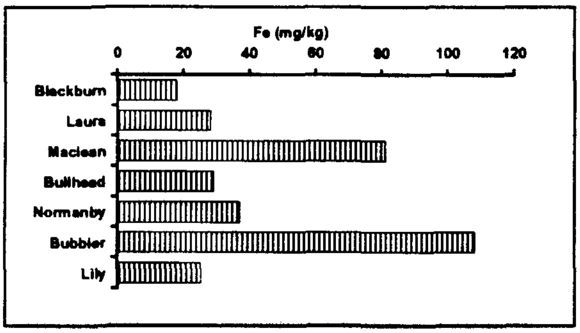

Figure 20 DTPA extractable iron in the surface (0-10 cm) of Lakeland Downs soils

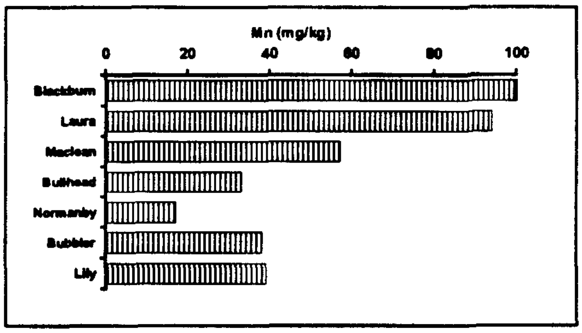

Figure 21 DTPA extractable manganese in the surface (0-10 cm) of Lakeland Downs soils

measured in the surface of Maclean and Bubbler (Figure 20). By contrast, the manganese levels appear to be in inverse proportion to the content of manganiferous and ferromanganiferous nodules observed in the soil in the field, particularly in the Blackburn, Laura, Maclean and Bullhead soils (Figure 21). All values exceed those required by crop plants likely to be grown in the area. Copper levels are similar across all soils (Figure 22). Values are adequate for most crops likely to be grown at Lakeland Downs and should not require supplementation with copper fertilisers. Zinc levels are variable with the highest values associated with those sites where there had been little or no cropping - Normanby and Maclean (Figure 23). The zinc levels in Lily are low. Fertilisation is likely to be required in this soil.

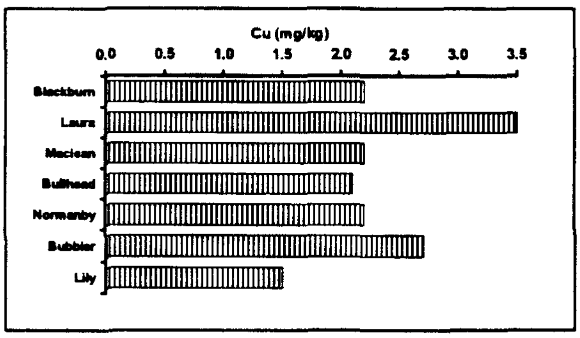

Figure 22 DTPA extractable copper in the surface (0-10 cm) of Lakeland Downs soils

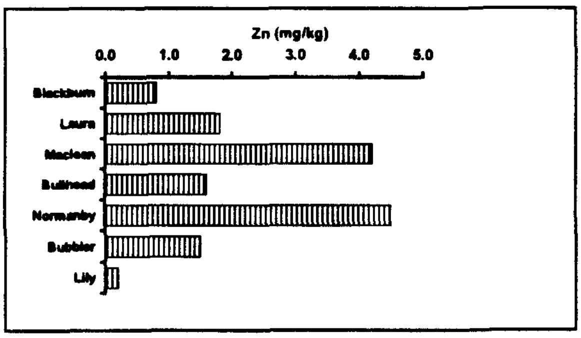

Figure 23 DTPA extractable zinc in the surface (0-10 cm) of Lakeland Downs soils

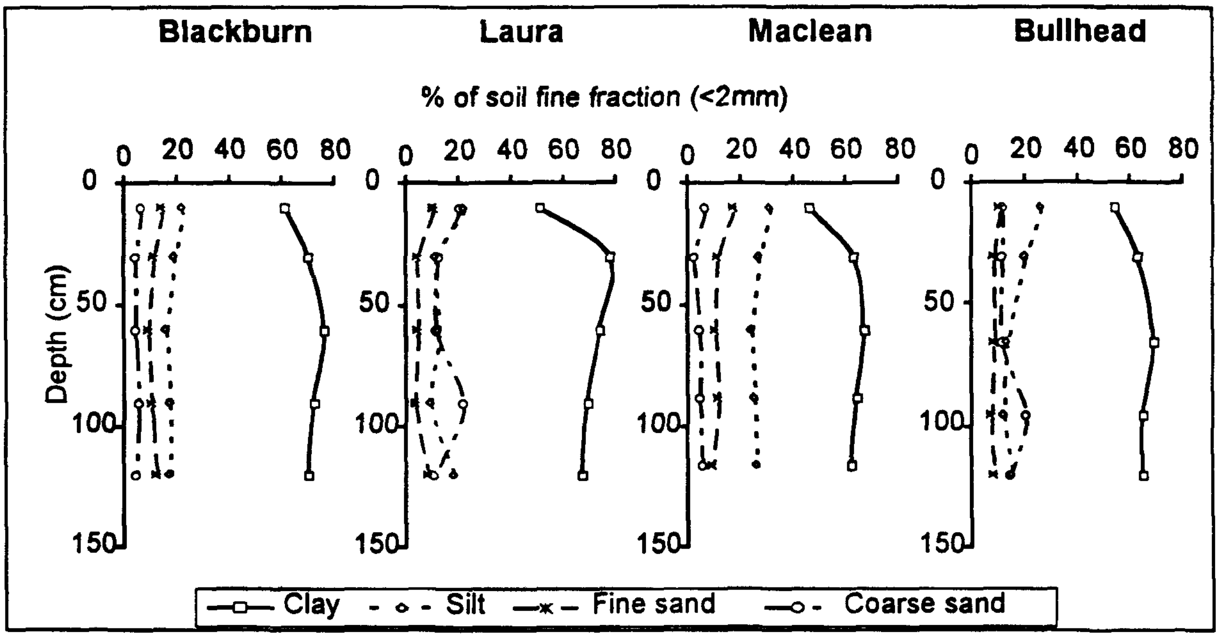

Figure 24 The distribution of clay, silt and sand in the Blackburn, Laura, Maclean and Bullhead soils from Lakeland Downs

5.2 Soil physics and soil water

Particle size distribution

The deep red and brown soils of Lakeland Downs, Blackburn, Laura, Maclean and Bubbler, are dominated in the fine fraction by clay (Figure 24). Clay contents tend to be lower in the surface horizons rising to about 60-70% throughout the B horizon. The relatively higher coarse fraction content in Laura and to a lesser extent, Maclean and Bullhead, is probably dominated by small, hard ferromanganiferous nodules which were not able to be separated before analysis rather than basalt stones.

While the proportion of size classes for these soils are relatively similar, the activity of the clay fraction is not. The ratio of CEC to clay is an indication of the activity of the clay minerals and therefore an indirect method of estimating clay mineralogy. Figure 25 illustrates that all of the Blackburn, Laura, Maclean and Bullhead soils have higher CEC/clay levels in the surface due to the presence of colloidal organic matter in this layer and all decline with depth. Maclean has the highest surface level

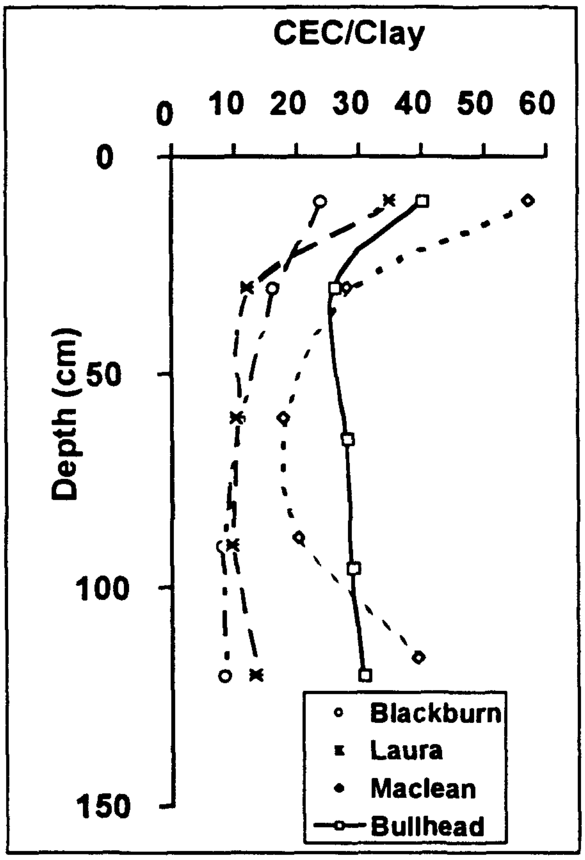

Figure 25 The ratio of CEC to clay for the Blackburn, Laura, Maclean and Bullhead soils of Lakeland Downs

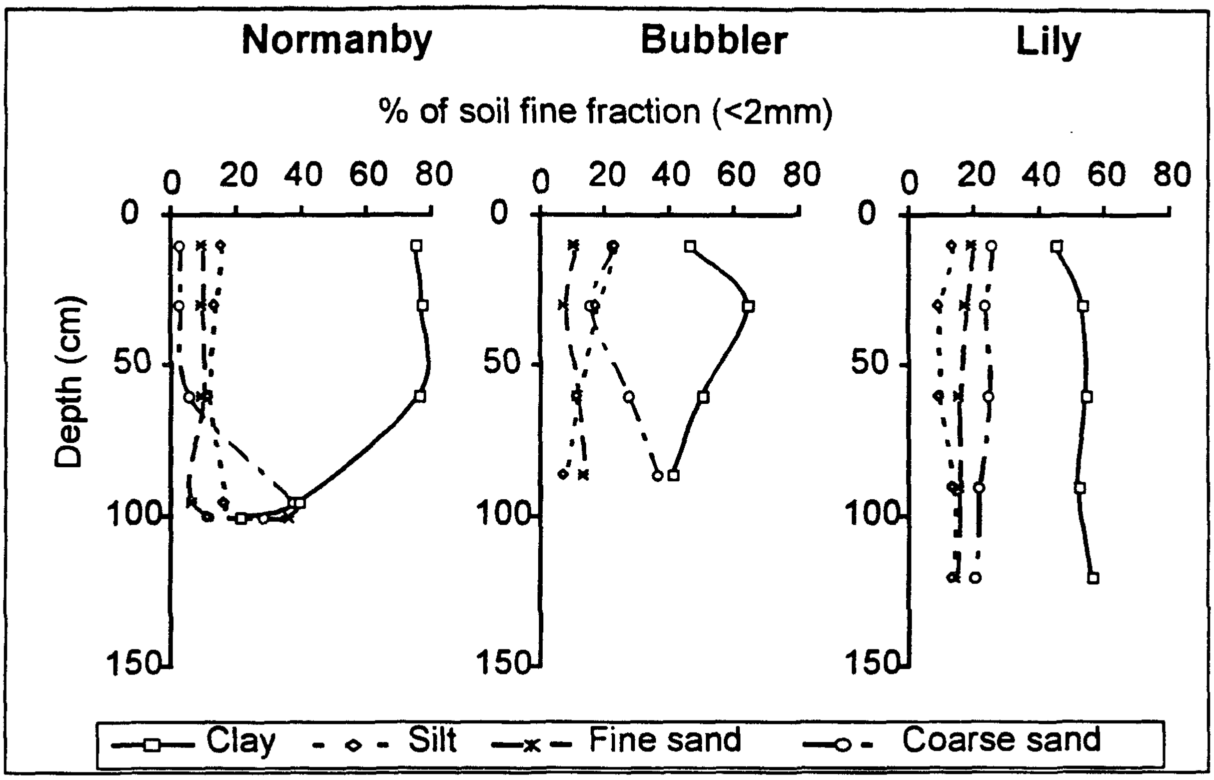

Figure 26 The distribution of clay, silt and sand in the Normanby, Bubbler and Lily soils from Lakeland Downs

whereas the other soils had been recently cropped. Both Laura and Blackburn soils decline to a value around 10 throughout the B horizon. This value is consistent with the clay fraction being dominated by kaolinite and suggests soil formation under high leaching conditions. The brown and/or mottled soils, Maclean and Bullhead, have appreciably higher levels of CEC per unit of clay. The clay fraction presumably contains significant levels of illitic or higher activity clays. These higher levels tend to correlate with a greater potential to absorb plant nutrients and soil moisture but they are also associated with reduced permeability and therefore longer periods of soil wetness.

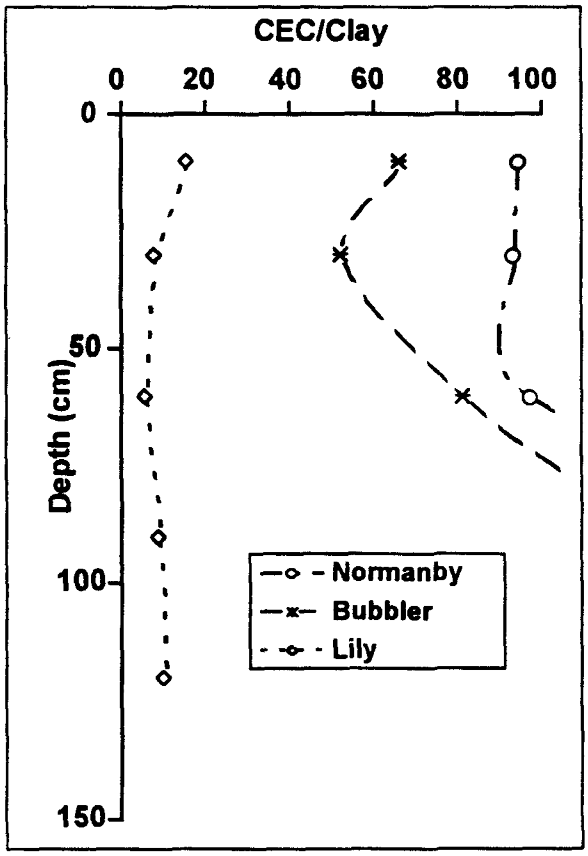

Figure 27 The ratio of CEC to clay for the Normanby, Bubbler and Lily soils of Lakeland Downs

The three remaining soils, Normanby, Bubbler and Lily differ from the first group and from each other (Figure 26). Normanby and Bubbler both grade into decomposing basalt at depth which is reflected in the decline in clay content at depth. Most Normanby soils described during field survey, however, were deeper. Clay contents exceed 60% down the soil profile. Bubbler increases in clay content from the surface to the B horizon. It has high levels of clay in the fine fraction where the soil proper has formed and declines where the soil grades into decomposing basalt. Lily is relatively uniform throughout the profile with the clay size class dominant.

Normanby has the highest levels of CEC per unit of clay measured at Lakeland Downs (Figure 27). The values which approach and exceed 100 suggest a dominance of montmorillonite in the clay mineralogy, the cause of the strong shrink-swell behaviour of this soil. Bubbler levels in the soil above the horizons dominated by decomposing rock suggest relatively high levels of 2:1 lattice clay types such as illite. The Lily levels are low throughout the profile with a slight increase due to colloidal organic matter in the surface. Clearly, kaolinite and sesquioxides dominate the clay materials.

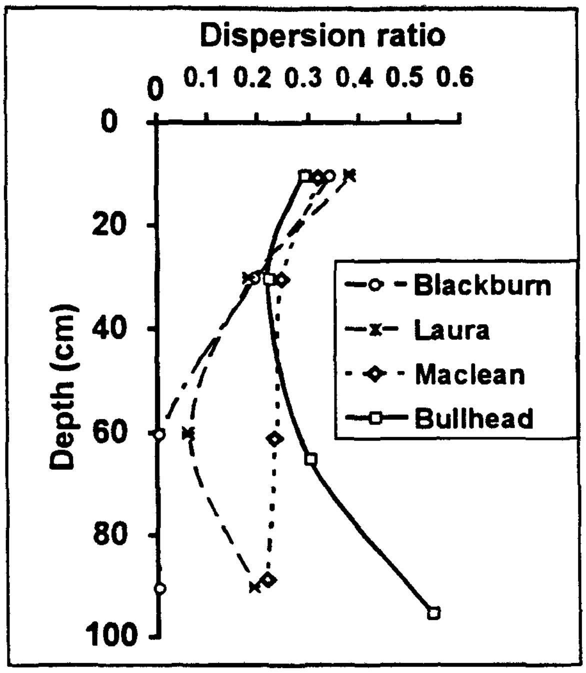

Figure 28 The ratio of dispersed silt and clay to total silt and clay (dispersion ratio) for the Blackburn, Laura, Maclean and Bullhead soils of Lakeland Downs

Dispersion

This discussion in based on the dispersion ratio (the ratio of silt and clay dispersed after an hour of end over end shaking to the total of silt and clay). Dispersion in the field is a complex process which is difficult to estimate from laboratory techniques. The tendency to disperse as measured by the dispersion ratio is correlated to the morphological features used in delineating the soils and in other attributes such as cation chemistry and mineralogy. Other factors such as exposure to physical disruption (raindrop impact, compaction and disturbance associated with cultivation) and the rooting pattern of the crop are also important and may not be correlated in the same way.

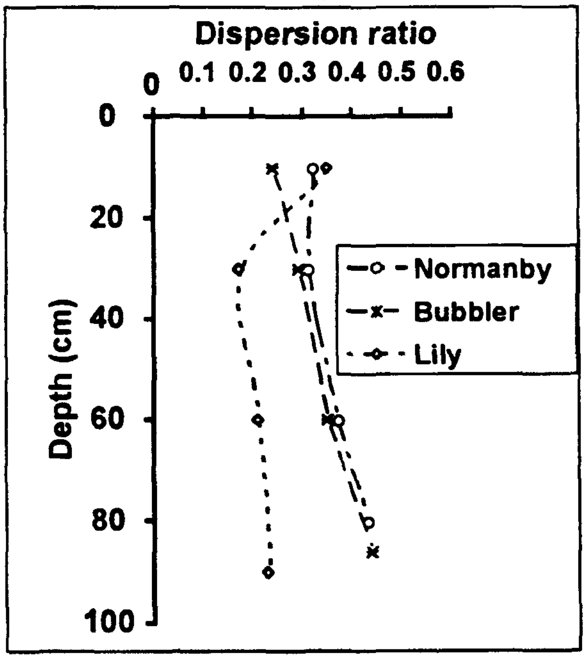

Figure 29 The ratio of dispersed silt and clay to total silt and clay (dispersion ratio) for the Normanby, Bubbler and Lily soils of Lakeland Downs

All the deep red and brown soils have similar ratios in the surface reflecting the over-riding influence of organic matter on this measure (Figure 28). Dispersion then declines rapidly in the well structured Blackburn and Laura soils to about 60 cm. The lower depths of Blackburn are extremely water stable and remain flocculated with shaking and immersion. In contrast, the lower depths of Laura, where iron and manganese nodules increase markedly, increase in dispersion although the level is still low. Both Maclean and Bullhead are more dispersive at depth with Bullhead increasing markedly in the horizons where sodium levels increased as a proportion of the exchange. None of the surface data suggest that dispersion is a significant problem in these soils in terms of crusting following cultivation. The higher levels in Bullhead at depth suggest that water movement through the profile will be restricted.

Of the remaining soils, Lily has a similar profile to Maclean, with relatively high levels in the surface, declining and then evening out with depth (Figure 29). This is despite the fact that this is the most sodic of the Lakeland Downs soils and illustrates that in low activity clays and with low absolute levels of cations, sodicity can be overestimated. Normanby and Bubbler have similar profiles. Both increase steadily and in a linear fashion. It was observed during field survey that Normanby also slakes quickly when peds are immersed in water. In both of these soils, the lower values were measured in soil with a significant component of decomposing basalt.

Water holding capacity

The water holding capacity of these soils were not measured. More intensive studies in the Ravenshoe area (Grundy *et al.* 1994) suggest that all of the structured soils (that is all soils except Lily) would have a high plant available water capacity (PAWC) per unit volume of soil. That capacity would be limited in those cases where soil depth is one metre or less. Estimated values for each soil is given in Table 3.

Table 3 Estimated plant available water capacity (PAWC) for the Lakeland Downs soils

Soil Profile Class	Estimated PAWC range (mm/1.5 m)	Reference	Comments
Blackburn	240 - 300	Grundy *et al.* (1994)	values inferred from similarity to Kaban soil mapped by Heiner and Grundy (1994)
Laura	240 - 300	Grundy *et al.* (1994)	values inferred from similarity to Kaban soil mapped by Heiner and Grundy (1994)
Maclean	200 - 300	none	values inferred from similarity to Blackburn and Laura. Lower value reflects the field observation of shallower members of this soil
Bullhead	150 - 200	none	values inferred from similarity to Blackburn and Laura - lower values inferred due to weaker structure and suspected reduced rooting depth due to seasonal waterlogging. Lower value reflects the field observation of shallower members of this soil
Normanby	100 - 230	Grundy *et al.* (1994)	lower values apply to shallower members of this group
Bubbler	50 - 100	none	shallowness is the overriding feature in this soil
Lily	100-150	none	Lily is an unusual soil and field measured data are not available for a comparable soil. Low estimates reflect the seasonal waterlogging associated with the soil

5.3 Limitations to agricultural land use

Detailed land suitability information was not collected as part of this study. It is possible, however, to make some generalisations of the capacity of the soils to support the principle agricultural industries in the area. It is intended that a complementary survey will derive the detailed information necessary to provide definitive land suitability analysis. Table 4 lists the limitations and the expected effect based on the land suitability scale (1 to 5 where 1 implies negligable limitation and 5 severe) for the dominant land uses at Lakeland Downs.

No data were available for some potential limitations. These include the potential for salinity through groundwater rise. No appreciable level of salt was identified in any soil profile but salt sources may well lie outside the sampled soil profile.

Table 4 Limitation classes associated with soils at Lakeland Downs. Values from 1 to 3 imply suitability for the dominant agricultural enterprises of the area, 4 and 5 have such severe limitations as to be unsuitable. Details of the suitability schema are in Appendix 3.

	Blackburn	Laura	Maclean	Bullhead	Normanby	Bubbler	Lily
moisture	1	1	1	1 to 2	1 to 2	3 to 4	2 to 4
erosion	1 to 3	1 to 2	1 to 3	1 to 3	1 to 2	3 to 4	1 to 3
wetness	1	1	2	3	2 to 3	1 to 3	3 to 4
rockiness	1 to 2	1 to 3	1 to 2	1 to 2	1 to 2	1 to 3	1 to 2
nutrition	1	1	1	1	1	1	2
intake/ outflow	α	α			β		
surface condition	1	1	1	1	1 to 2	1	1
complexity	1	1	1	1	1 to 4	1	1
microrelief	1	1	1	1	1 to 2	1	1
adhesiveness	1	1	1	1	1 to 3	1	1 to 2
Land Suitability Class	**1 to 3**	**1 to 3**	**2 to 3**	**3**	**2 to 4**	**3 to 4**	**3 to 4**

[α] These soils occur in landscape positions, and have sufficient permeability, for intake to the water table or groundwater to occur. No data exist as to the likelihood or the consequence of this occurring.

[β] These soils occur in landscape positions, and have sufficiently reduced permeability, for outflow from heightened water tables to occur. No data exist as to the likelihood or the consequence of this occurring.

Blackburn and Laura have the smallest number of potential limitations and the widest range of potential agricultural land uses. In many occurrences of these soils and for a broad range of cropping and pastoral activities, no significant limitations exist. Some of these soils occur on slopes, and hence require management practices such as appropriate soil conservation structures and soil surface management to reduce water erosion; in some instances, the presence of rocks either results in the direct cost of rock picking or adds to costs in machinery damage. Where these limitations occur, the land suitability for affected land uses (*eg.* cropping systems involving cultivation; root crops) is reduced to 2 or 3. In other cases, these are class 1 soils.

Maclean and Bullhead have a similar range of limitations to Blackburn and Laura with the addition of wetness. Thus the potential for water erosion and damage by rocks is present in some areas where these soils occur, and land suitability is reduced for affected land uses. The potential for wetness is greater in Bullhead than in Maclean, but in both the effect is to reduce the length of time available for wheeled traffic on these soils and, in sensitive crops, to affect yields due to poor aeration. The soils remain suitable but the rating of 2 in the case of Maclean and 3 in the case of Bullhead indicates that there are added costs associated with these soils that are not associated with Blackburn and Laura.

The cracking clay soil Normanby has a wider range of limitations than the other soils but in many instances and for some land uses, this is also a highly suitable soil. The only limitation which makes areas of this soil unsuitable is complexity. Some of the occurrences of Normanby are small and surrounded by unsuitable land making the use of the land uneconomic. In most areas, the major limitation is wetness; opportunities for planting on this soil would be significantly reduced relative to the well drained red soils. The clay type in this soil is strongly adhesive, adding to the costs of producing root crops. In particular instances, there are also limitations due to the potential for water erosion, rocks and reduced soil depth which has a direct effect on plant stability and indirectly on the PAWC.

The Bubbler soil is shallow and tends to occur on the higher sloping areas on Lakeland Downs. Consequently, it is prone to water erosion and is limited in its ability to provide water to plants. The deeper and less sloping occurrences of this soil are suitable for a limited range of agricultural land uses with moderate limitations. For most purposes, the erosion and moisture limitations make this a marginal soil.

Lily is by far the soil with the greatest nutritional limitations, but its most significant limitations to agricultural land use are its tendency to seasonal wetness, its limited ability to supply moisture and, in some situations, its tendency to erode. The better drained members of this group, on lower slopes, are suitable for some uses with moderate limitations.

6. Conclusions

The soils of the basalt landforms of Lakeland Downs range from deep, well drained soils to shallow, poorly drained soils. The most common soils are Blackburn and Laura, deep Ferrosol soils (Euchrozems in Great Soil Group terminology) with moderate fertility and high water holding capacity. These soils have minor limitations to irrigated agriculture or rain-fed agriculture, provided adequate rainfall is received. Other soils which are suitable for a wide range of agricultural uses include Maclean and Bullhead (soils with a higher degree of seasonal wetness). Normanby, a cracking clay soil, is suitable for grain crops where there is a sufficiently large area of the soil. Other soils include Bubbler, a shallow soil with significant erosion and moisture capacity limitations, and Lily, a poorly drained soil with low levels of plant nutrients.

Most of the soils are not easily identified from an examination of the surface and can not be reliably predicted from the position in the landscape. Consequently, a key is provided to aid identification from small holes or exposures.

7. Acknowledgments

The authors acknowledge the important assistance of Mr Jim Klein, DPI Mareeba, for assistance during the initial field stages, and of the staff of Agricultural Chemistry in DPI.

Editorial comment was received from Mr John Maher, Mr Doug Smith and Mr Dennis Baker and is appreciated.

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Appendix 1 Soil Profile Classes

Soil Profile Classes are named classes of soils with explicit ranges of soil attributes. They are derived by grouping soil morphological data into recurring classes i.e. they are a soil classification derived from the land, not imposed on it. At Lakeland Downs, seven soils were identified based on 74 field descriptions of soil profiles. These soils encompass almost all the variation observed in the soils at Lakeland Downs to this stage. More detailed survey may identify important soil profiles which lie outside these ranges of attributes, but the number is unlikely to be large. Soil Profile Classes allow the choice of individual profiles which are likely to be representative of the soils of the area. They are a powerful communication tool to extend the significant concepts and attributes identified during the survey process.

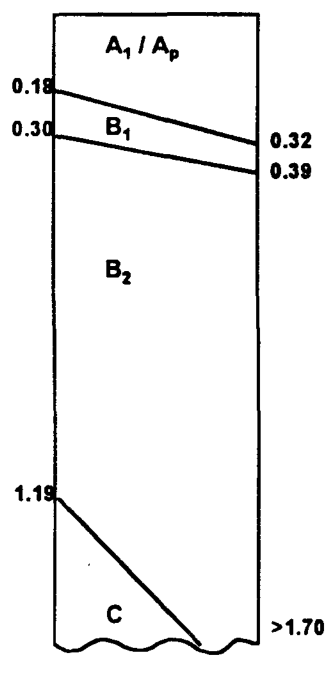
An example profile from each Soil Profile Class was sampled for detailed chemical and physical analysis. These data are listed in the same order in Appendix 2.

Notes on the descriptions:

1. *The descriptions are drawn from field observations of soils which fall within the concept of the soil profile class. The number of observations differ between soils.*
2. *Black horizontal or diagonal lines indicate the range over which major changes in soil horizons were identified in the field. Grey lines are used in some instances to indicate that the change occurred in some but not all soils examined.*
3. *All depth units are in metres.*

BLACKBURN Soil Profile Class

Concept:	*A deep, red, structured, clay soil formed on weathering basalt. There are no mottles or nodules and pH is neutral at depth*



Principal Profile Form: Uf6.31, Gn3.12
Great Soil Group: Euchrozem
Australian Soil Classification: Haplic, mesotrophic, red Ferrosol
Landform: Lava plain **Parent Material:** Basalt
Dominant vegetation / land use: Cultivation, dryland

A_1 or A_p red or dark, light clay to light medium clay, moderate fine blocky or polyhedral structure, very few fine ferromanganiferous nodules in some profiles, acid, clear change to -

B_1 (where present) red, light medium clay to medium heavy clay, moderate to strong fine polyhedral structure, very few fine ferromanganiferous nodules in some profiles, slightly acid, gradual change to -

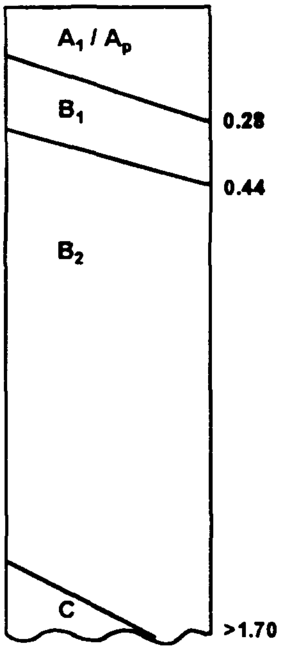
B_2 red, light clay to medium clay, moderate to strong fine polyhedral structure, very few ferromanganiferous nodules in some profiles, neutral, gradual change to -

C (where present) weathering basalt

Some profiles have a few soft manganiferous segregations at depth

LAURA Soil Profile Class

Concept: *A deep, red, structured, clay soil formed on weathering basalt. There are numerous iron and manganese nodules but no mottles and pH is neutral at depth*



Principal Profile Form: Uf6.31, Gn3.12
Great Soil Group: Euchrozem
Australian Soil Classification: Haplic, mesotrophic, red Ferrosol
Landform: Lava plain **Parent Material:** Basalt
Dominant vegetation / land use: Cultivation, dryland

A_1 or A_p dark or red, light clay, moderate fine blocky structure, very few fine ferromanganiferous nodules, acid, clear change to -

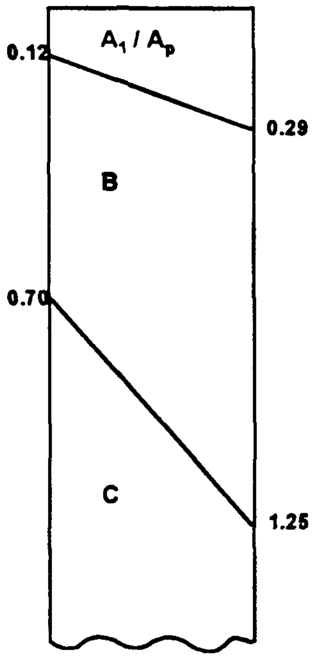
B_1 (where present) red, light clay to light medium clay, moderate to strong fine blocky structure, very few to few fine or medium ferromanganiferous nodules, slightly acid, gradual change to -

B_2 red, light clay to medium clay, weak to strong fine polyhedral structure with stronger structure more evident in upper part of the B_2 horizon in most profiles, few to many ferromanganiferous nodules throughout increasing in proportion and size with depth, neutral, gradual change to -

C (where present) weathering basalt

MACLEAN Soil Profile Class

Concept: *A deep, brown, structured, clay soil formed on weathering basalt. There are some iron and manganese nodules and mottles and pH is neutral at depth*



Principal Profile Form: Gn3.22, Uf6.31, Gn 3.11
Great Soil Group: No suitable group, affinities with euchrozem
Australian Soil Classification: Haplic, eutrophic, brown or red Ferrosol
Landform: Lava plain **Parent Material:** Basalt
Dominant vegetation / land use: Cultivation, dryland

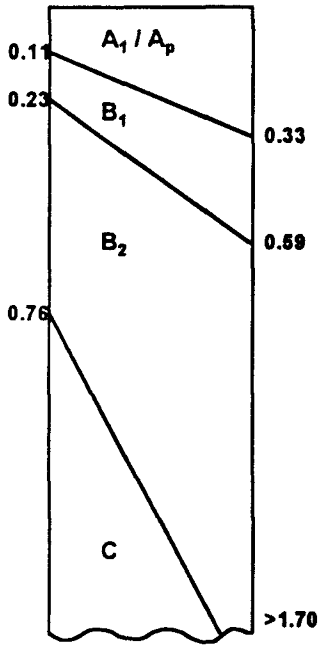
A_1 or A_p dark or red-brown, clay loam to light clay, moderate fine blocky structure, very few fine ferromanganiferous or manganiferous nodules in some profiles, acid, clear change to -

B_1 brown or red brown with very few to common red or yellow mottling in deeper layers, light clay to medium clay, moderate to strong fine blocky or polyhedral structure, fine or medium ferromanganiferous and manganiferous nodules increasing with depth, few basalt pebbles in deeper layers, acid becoming neutral with depth, gradual change to -

C weathering basalt

BULLHEAD Soil Profile Class

Concept: *A deep, brown or yellow, structured, clay soil formed on weathering basalt. There are numerous iron and manganese nodules and red and yellow mottles and pH is neutral at depth*



Principal Profile Form: Uf6.34, Uf6.31, Gn3.22, Gn2.12
Great Soil Group: Xanthozem
Australian Soil Classification: Haplic, eutrophic, red or brown Dermosol
Landform: Lava plain **Parent Material:** Basalt
Dominant vegetation / land use: Cultivation, dryland

A_1 or A_p — dark or red-brown, clay loam to light clay, weak to moderate fine blocky structure, few or very few fine or medium ferromanganiferous nodules, acid, clear change to -

B_1 — red to brown, clay loam to light clay, massive or fine moderate blocky or polyhedral structure, very few fine or medium ferromanganiferous nodules, acid , clear change to -

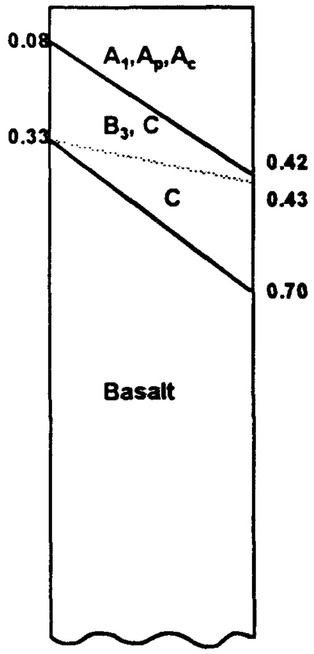
B_2 — red to yellow-brown becoming more yellow with depth, with yellow or red mottling increasing in proportion, size and distinctness with depth, light clay to light medium clay, weak to moderate fine blocky or polyhedral structure becoming stronger and more complex with depth, few to many ferromanganiferous nodules increasing in size with depth, acid to neutral, clear or gradual change to -

C — (where present) weathering basalt

A heavy clay D horizon is present below 1.2m in some profiles

BUBBLER Soil Profile Class

Concept: *A shallow, red to brown, weakly structured, clay soil formed on weathering basalt. There are numerous iron and manganese nodules and basalt gravel and pH is neutral at depth*



Principal Profile Form: Uf6.53, Uf6.71
Great Soil Group: No suitable group, affinities with (shallow) prairie soil
Australian Soil Classification: Haplic, eutrophic, brown or red Kandosol
Landform: Lava plain**Parent Material:** Basalt
Dominant vegetation / land use: Cultivation, dryland

A_1, AC or A_p — brown, light clay, weak to moderate blocky structure, many small ferromanganiferous nodules, few to many basalt gravel and cobbles, acid, gradual change to -

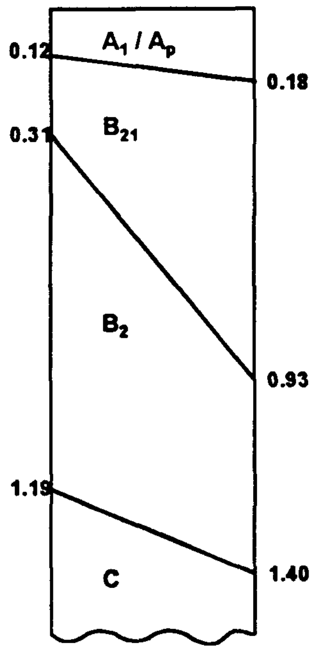
B_3 — (where present) red or brown, light clay to light medium clay, weak to moderate blocky structure, many small ferromanganiferous nodules, many basalt gravel and cobbles, acid, clear or gradual change to -

C — weathering basalt

NB: The grey line in the diagram indicates a change in horizons that is not always present in this soil profile class

NORMANBY Soil Profile Class

Concept: *A dark or grey cracking clay soil formed on weathering basalt. There are some fine iron and manganese nodules and basalt gravel and pH is alkaline at depth*



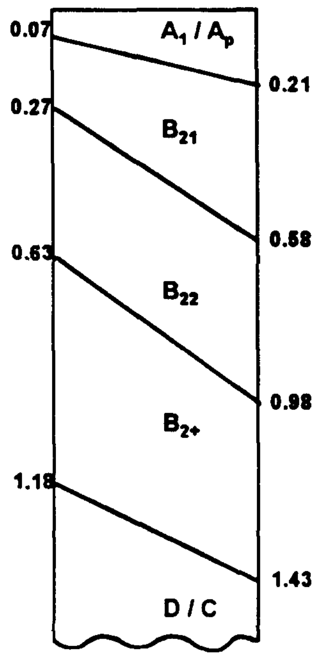
Principal Profile Form: Ug5.12, Ug 5.13, Ug 5.23, Ug5.26
Great Soil Group: Black earth, grey clay
Australian Soil Classification: Haplic, self-mulching, grey or black Vertosol
Landform: Lava plain **Parent Material:** Basalt
Dominant vegetation / land use: Complete clearing, cultivation at some stage, grazing by hoofed animals

A_1 or A_p	dark, medium to medium heavy clay, strong granular structure, few small ferromanganiferous nodules in some profiles, acid, clear change to -
B_{21}	dark or grey-brown, medium heavy clay, weak 10-20mm lenticular secondary structure breaking to moderate to strong 2-5mm blocky primary structure, very few small ferromanganiferous nodules, slightly acid to neutral, diffuse or gradual change to -
B_2	dark or grey-brown, medium heavy clay to heavy clay, weak to moderate 10-50mm lenticular secondary structure breaking to moderate to strong 2-5mm blocky primary structure, very few small ferromanganiferous nodules, few to many carboniferous nodules, alkaline, clear or gradual change to -
C	weathering basalt

B_3 and BC horizons are present in shallow variants at 0.70 to 0.90m

LILY Soil Profile Class

Concept: *A deep, yellow or brown soil with a massive upper B horizon. There are fine iron and manganese nodules and red mottles and pH is neutral at depth*



Principal Profile Form: Gn2.22, Gn2.42, Uf6.71, Uf6.72
Great Soil Group: No suitable group, affinities with yellow earth
Australian Soil Classification: Sodic, mesotrophic, brown or yellow Kandosol
Landform: Lava plain **Parent Material:** non-basaltic colluvium
Dominant vegetation / land use: Cultivation, dryland

A_1 or A_p	dark or brown, clay loam to light clay, massive to weak blocky structure, few ferromanganiferous nodules, acid, clear or gradual change to -
B_{21}	brown, yellow-brown or yellow, clay loam to light clay, massive structure, few to many ferromanganiferous nodules, slightly acid, gradual change to -
B_{22}	brown, clay loam, massive or weak polyhedral structure, few to many ferromanganiferous nodules, slightly acid, gradual change to -
B_{2+}	yellow or brown with few to common orange and red mottles, clay loam to light clay, massive to moderate polyhedral structure, few to very many ferromanganiferous nodules increasing with depth, slightly acid to neutral, abrupt or clear change to -
D	(where present) brown with few red mottles, heavy clay, strong polyhedral structure, few to many ferromanganiferous nodules, alkaline

Variations: A_2 horizons are sometimes present; some profiles have buried 2B and 2C horizons

Appendix 2 Descriptions of sampled profiles

SOIL TYPE: Blackburn SUBSTRATE MATERIAL: Basalt SITE NO: S2
A.M.G. REFERENCE: 269 700 mE 8 251 400 mN ZONE 55 SLOPE: 0.8 %
GREAT SOIL GROUP: Euchrozem
PRINCIPAL PROFILE FORM: Uf6.31 LANDFORM PATTERN TYPE: Gently undulating plain

PROFILE MORPHOLOGY:

CONDITION OF SURFACE SOIL WHEN DRY: Firm

HORIZON	DEPTH	DESCRIPTION
AP1	0 to .13 m	Very dark reddish brown (2.5YR2/4) moist; light medium clay; moderate 2-5mm polyhedral secondary, parting to weak <2mm polyhedral primary. Clear to-
AP2	.13 to .18 m	Very dark reddish brown (2.5YR2/4) moist; light medium clay; weak 5-10mm polyhedral. Clear to-
B1	.18 to .30 m	Dark reddish brown (2.5YR3/4) moist; medium heavy clay; weak 5-10mm polyhedral secondary, parting to moderate 2-5mm polyhedral primary. Gradual to-
B21	.30 to .45 m	Dark reddish brown (2.5YR3/4) moist; medium clay; moderate 2-5mm polyhedral. Gradual to-
B22	.45 to .70 m	Dark reddish brown (2.5YR3/4) moist; medium heavy clay; strong 5-10mm polyhedral. Gradual to-
B23	.70 to 1.13 m	Dark red (10R3/4) moist; medium clay; moderate 2-5mm polyhedral secondary, parting to weak <2mm polyhedral primary. Gradual to-
B24	1.13 to 1.30 m	Dark reddish brown (2.5YR3/6) moist; medium clay; moderate 2-5mm polyhedral secondary, parting to moderate <2mm polyhedral primary. Gradual to-
B25	1.30 to 1.50 m	Dark reddish brown (2.5YR3/6) moist; light medium clay; moderate 2-5mm polyhedral.

Laboratory data:

Depth	1:5 Soil/Water			Particle size					Exchangeable Cations				Moistures		Disp	Total Element		
(m)	pH	EC mS/cm	Cl %	CS	FS	S	C	CEC	Ca	Mg	Na	K	ADM	15mP	Ratio R1	P	K	S
				% @ 105°C					meq/100g soil				% @ 105°C			%		
0.10	6.5	0.04	0.001	6	14	22	61	14.5	10	2.9	0.05	1.5	5	23	0.34	0.17	0.26	0.03
0.30	6.5	0.04	0.001	4	11	19	70	11.3	7.6	2.7	0.05	0.9	8.8	25	0.19	0.11	0.19	0.02
0.60	6.2	0.10	0.002	4	9	16	76	7.99	5.4	2.1	0.05	0.44	4.7	25	flocc	0.09	0.15	0.01
0.90	6 3	0.03	0.001	5	10	17	72	5.63	3.7	1.5	0.05	0 38	4.7	24	flocc	0.1	0 11	0.01
1.20	6.5	0.02	0.001	4	12	17	70	5.63	3.6	1.6	0.05	0.38	6.3			0.1	0.1	0.01
1.50	6.4	0.01	0.001										3 5					

Bulked surface sample	Org. C (W&B) %	Total N %	Extr. P Acid (ppm)	Extr. P Bicarb (ppm)	Rep. K meq%	DTPA extr. Fe (ppm)	DTPA extr. Mn (ppm)	DTPA extr. Cu (ppm)	DTPA extr. Zn (ppm)
(0-10cm)	2	0.15	52	40	1.2	18	100	2.2	0.8

SOIL TYPE: **Laura** SUBSTRATE MATERIAL: Basalt SITE NO: S1
A.M.G. REFERENCE: 255 400 mE 8 251 900 mN ZONE 55 SLOPE: 0 %
GREAT SOIL GROUP: Euchrozem
PRINCIPAL PROFILE FORM: Uf6.31 LANDFORM PATTERN TYPE: Level plain
SURFACE COARSE FRAGMENTS: Very few basalt pebbles

PROFILE MORPHOLOGY:

CONDITION OF SURFACE SOIL WHEN DRY: Firm

HORIZON	DEPTH	DESCRIPTION
A1	0 to .09 m	Very dark brown (7.5YR2/3); light clay; single grain; very few medium ferruginous nodules. Clear to-
B21	.09 to .17 m	Dark reddish brown (10R3/3); medium clay; single grain; very few fine ferruginous nodules. Clear to-
B22	.17 to .30 m	Dark red (10R3/4); medium clay; weak 5-10mm polyhedral secondary, parting to moderate 2-5mm polyhedral primary; very few medium ferruginous nodules. Gradual to-
B23	.30 to .40 m	Dark red (10R3/4); medium clay; weak 2-5mm polyhedral; few medium ferruginous nodules. Gradual to-
B24	.40 to .75 m	Dark red (10R3/4); medium clay; moderate 10-20mm subangular blocky secondary, parting to moderate 2-5mm polyhedral primary; few medium ferruginous nodules. Gradual to-
B25	.75 to 1.23 m	Dark red (10R3/4); light medium clay; strong 2-5mm polyhedral; few medium ferruginous nodules.

Laboratory data:

Depth	1:5 Soil/Water			Particle size					Exchangeable Cations				Moistures		Disp	Total Element		
(m)	pH	EC	Cl	CS	FS	S	C	CEC	Ca	Mg	Na	K	ADM	15mP	Ratio	P	K	S
		mS/cm	%		% @ 105°C				meq/100g soil				% @ 105°C		R1		%	
0.10	6 9	0.04	0 001	20	10	22	51	17 8	13	3.3	0.06	1.4	4.2	20	0.38	0.18	0.39	0.03
0.30	6.8	0.02	0.001	12	4	11	78	9.43	7	1.8	0.06	0.57	3 7	24	0.18	0.08	0.23	0.01
0.60	6.7	0.02	0.002	11	4	12	74	7 68	5.9	1.3	0.05	0.43	3.41	25	0.06	0.08	0.17	0.01
0.90	6.9	0.01	0.001	21	3	9	69	6.64	5 2	1	0 05	0.39	3.82	22	0.19	0.09	0.16	0.01
1.20	6.9	0.01	0.001	10	8	18	67	8 94	6 9	1.6	0.06	0.38	4.41			0.08	0 14	0.01

Bulked surface sample	Org. C (W&B) %	Total N %	Extr. P Acid ppm	Extr. P Bicarb ppm	Rep. K meq%	DTPA extr. Fe ppm	DTPA extr. Mn ppm	DTPA extr. Cu ppm	DTPA extr. Zn ppm
(0-10cm)	2.6	0.16	88	64	1 7	28	94	3 5	1 8

SOIL TYPE: Maclean SUBSTRATE MATERIAL: Basalt SITE NO: S3
A.M.G. REFERENCE: 269 400 mE 8 238 900 mN ZONE 55 SLOPE: 2.8%
GREAT SOIL GROUP: No suitable group. Affinities with krasnozem
PRINCIPAL PROFILE FORM: Gn3.11 LANDFORM PATTERN TYPE: Level plain
SURFACE COARSE FRAGMENTS: Very few basalt pebbles

PROFILE MORPHOLOGY:

CONDITION OF SURFACE SOIL WHEN DRY: Firm

HORIZON	**DEPTH**	**DESCRIPTION**
A1	0 to .18 m	Dark reddish brown (2.5YR2/3) moist; clay loam; moderate 2-5mm subangular blocky. Clear to-
B1	.18 to .35 m	Reddish brown (5YR4/4) moist; medium clay; moderate 5-10mm angular blocky secondary, parting to weak 2-5mm polyhedral primary. Gradual to-
B21	.35 to .66 m	Reddish brown (5YR4/4); medium clay; moderate 5-10mm polyhedral secondary, parting to weak 2-5mm polyhedral primary; very few fine manganiferous nodules. Gradual to-
B22	.66 to .88 m	Reddish brown (5YR4/4) moist; light clay; moderate 5-10mm subangular blocky; few medium manganiferous nodules. Gradual to-
B23	.88 to 1.00 m	Reddish brown (5YR4/4) moist; few fine distinct red mottles; light clay; weak 5-10mm polyhedral; very few fine manganiferous nodules. Clear to-
B24	1.00 to 1.16 m	Reddish brown (5YR4/4) moist; very few fine faint red mottles; light clay; few medium pebbles, subrounded basalt; massive. Gradual to-
B3	1.16 to 1.25 m	Reddish brown (5YR4/2) moist; few fine distinct red mottles, very few fine distinct yellow mottles; light clay; abundant coarse pebbles, angular basalt; moderate 5-10mm subangular blocky. Clear to-

Laboratory data:

Depth	1:5 Soil/Water			Particle size					Exchangeable Cations				Moistures		Disp	Total Element		
(m)	pH	EC mS/cm	Cl %	CS	FS % @ 105°C	S	C	CEC	Ca	Mg meq/100g soil	Na	K	ADM % @ 105°C	15mP	Ratio R1	P	K %	S
0.10	6 6	0 07	0 001	6	17	31	46	26.4	16	7 6	0.06	2.7	7 9	24	0.32	0.51	0.31	0.03
0.30	6 7	0.02	0.001	2	11	27	63	17 8	12	5.5	0 07	0 26	8.3	25	0.24	0.42	0.12	0.02
0.60	6.8	0.02	0.002	4	10	24	67	12.1	7	4.9	0.1	0.07	6.3	25	0.23	0.28	0.09	0.01
0.88	6 7	0.02	0 002	4	11	25	64	12.9	6 8	5 9	0.14	0.1	7.2	26	0.21	0.29	0.08	0.01
1.16	7.3	0.02	0 001	5	9	26	62	24.4	12	12	0.32	0.09	5.8			0.27	0 04	0.01

Bulked surface sample	Org. C (W&B) %	Total N %	Extr. P Acid ppm	Bicarb	Rep. K meq%	DTPA extr. Fe ppm	Mn	Cu	Zn
(0-10cm)	2.7	0.24	250	275	1 8	81	57	2 2	4.2

SOIL TYPE: Bullhead SUBSTRATE MATERIAL: **Basalt** SITE NO: **S5**
A.M.G. REFERENCE: 269 800 mE 8 242 200 mN ZONE 55 SLOPE: 2.5 %
GREAT SOIL GROUP: No suitable group. Affinities with Xanthozem
PRINCIPAL PROFILE FORM: Gn2.12 LANDFORM PATTERN TYPE: Gently undulating rises
SURFACE COARSE FRAGMENTS: Small basalt pebbles

PROFILE MORPHOLOGY:

CONDITION OF SURFACE SOIL WHEN DRY: Recently cultivated, loose

HORIZON	**DEPTH**	**DESCRIPTION**
Ap1	0 to .19 m	Very dark reddish brown (5YR2/3) moist; clay loam; weak <2mm polyhedral; very few medium ferromanganiferous nodules. Clear to-
Ap2	.19 to .34 m	Dark reddish brown (5YR3/3) moist; light clay; weak 2-5mm polyhedral; very few fine ferromanganiferous nodules. Clear to-
B21	.34 to .54 m	Brown (7.5YR4/6) moist; light medium clay; weak <2mm angular blocky; few medium ferromanganiferous nodules. Clear to-
B22	.54 to .65 m	Dark reddish brown (5YR3/3) moist; light medium clay; weak <2mm angular blocky; very few fine ferromanganiferous nodules. Clear to-
B23	.65 to .84 m	Dark reddish brown (5YR3/4) moist; very few fine faint orange mottles; light medium clay; weak <2mm angular blocky; very few fine ferromanganiferous nodules. Gradual to-
B24	.84 to 1.64 m	Dark reddish brown (5YR3/4) moist; medium clay; moderate 5-10mm polyhedral secondary, parting to moderate 2-5mm polyhedral primary; few medium ferromanganiferous nodules.

Laboratory data:

Depth (m)	1:5 Soil/Water pH	EC mS/cm	Cl %	Particle size CS	FS	S	C	CEC	Exchangeable Cations Ca	Mg	Na	K	Moistures ADM	15mP	Disp Ratio R1	Total Element P	K	S
				% @ 105°C					meq/100g soil				% @ 105°C			%		
0.10	6 7	0.03	0.001	11	10	26	54	21 7	13	7 1	0.08	1 5	6.1	23	0.29	0.27	0.26	0.03
0.30	6.8	0.01	0.001	11	8	20	63	16.4	9.6	6.4	0.13	0.26	8.6	24	0.22	0.21	0.19	0 02
0.65	6.9	0.04	0 001	11	8	13	69	19.2	10	8.5	0.51	0.23	9.5	25	0.3	0.21	0.19	0.01
0.95	7.3	0.02	0.002	20	7	12	65	18.6	8.1	9.6	0.8	0.14	5.4	24	0.54	0.18	0.15	0.01
1.20	7.3	0.02	0.001	14	8	15	65	19.8	7.7	11	1.1	0.13	5.9			0 18	0.14	0 01
1.50	7.3												6					

Bulked surface sample	Org. C (W&B) %	Total N %	Extr. P Acid	Bicarb	Rep. K meq%	DTPA extr. Fe	Mn	Cu	Zn
			ppm					ppm	
(0-10cm)	1.5	0.13	23	33	0.8	29	33	2 1	1 6

SOIL TYPE: Normanby	SUBSTRATE MATERIAL:	**Basalt**		SITE NO:	S4
A.M.G. REFERENCE:	273 800 mE 8 246 000 mN	ZONE	55	SLOPE:	0.8 %

GREAT SOIL GROUP: Grey clay

PRINCIPAL PROFILE FORM: Ug5.23 LANDFORM PATTERN TYPE: Level plain

VEGETATION:

STRUCTURAL FORM: Mid-high isolated trees

DOMINANT SPECIES *Eucalyptus* species

PROFILE MORPHOLOGY:

CONDITION OF SURFACE SOIL WHEN DRY: Periodic cracking, self mulching

HORIZON	DEPTH	DESCRIPTION
A11	0 to .12 m	Brownish black (10YR3/1) moist; medium heavy clay; moderate 2-5mm prismatic. Gradual to-
A12	.12 to .16 m	Brownish grey (10YR4/1) moist; medium heavy clay; moderate 5-10mm prismatic secondary, parting to moderate <2mm prismatic primary. Clear to-
B21	.16 to .40 m	Brownish grey (10YR4/1) moist; many coarse distinct dark mottles; medium heavy clay; weak 20-50mm lenticular secondary, parting to strong <2mm angular blocky primary; few fine manganiferous soft segregations. Diffuse to-
B22	.40 to .60 m	Brownish grey (10YR4/1) moist; few medium prominent dark mottles; medium heavy clay; weak 20-50mm lenticular secondary, parting to weak <2mm angular blocky primary; very few fine manganiferous nodules, few fine manganiferous soft segregations. Diffuse to-
B23	.60 to .83 m	Brownish grey (10YR4/1) moist; very few medium distinct dark mottles; medium heavy clay; weak 20-50mm lenticular secondary, parting to weak <2mm angular blocky primary; very few fine manganiferous nodules, few fine manganiferous soft segregations. Clear to-
B3	.83 to .95 m	Dull yellowish brown (10YR4/3) moist; few medium distinct dark mottles; medium heavy clay; very few small pebbles, subangular quartz; common fine manganiferous soft segregations, very few fine manganiferous nodules.

Laboratory data:

Depth	1:5 Soil/Water			Particle size					Exchangeable Cations				Moistures		Disp	Total Element		
(m)	pH	EC	Cl	CS	FS	S	C	CEC	Ca	Mg	Na	K	ADM	15mP	Ratio	P	K	S
		mS/cm	%		% @ 105°C				meq/100g soil				% @ 105°C		R1		%	
0.10	6 4	0.02	0 001	2	9	15	75	70 5	49	21	0.2	0.33	13.2	39	0 32	0.29	0.1	0.02
0.30	6.4	0.02	0.001	2	9	13	77	71.4	52	19	0.26	0 18	13.2	40	0.31	0.26	0.08	0.02
0.60	6.5	0.02	0 001	5	9	11	76	73.5	55	18	0.32	0.15	14.9	41	0.37	0.26	0.07	0.01
0.80	6.5							76 5	58	18	0 34	0.17	11.8					
0.95	6 8	0.02	0.001	37	6	16	39	88 4	69	19	0 32	0.11	15.8	43	0.43	0.57	0.02	0.01
1.00	7 2	0.04	0.001	28	36	11	21	95.4	76	19	0.28	0.09	16.3			0.6	0.01	0.01

Bulked surface sample	Org. C (W&B) %	Total N %	Extr. P Acid ppm	Extr. P Bicarb ppm	Rep. K meq%	DTPA extr. Fe ppm	DTPA extr. Mn ppm	DTPA extr. Cu ppm	DTPA extr. Zn ppm
(0-10cm)	2.5	0.21	570	125	1.3	37	17	2.2	4 5

SOIL TYPE: **Bubbler** SUBSTRATE MATERIAL: Basalt SITE NO: S7
A.M.G. REFERENCE: 266 000 mE 8 242 000 mN ZONE 55 SLOPE: 1.5 %
GREAT SOIL GROUP: No suitable group. Affinities with Lithosol
PRINCIPAL PROFILE FORM: Uf6.53 LANDFORM PATTERN TYPE: Gently undulating rises
SURFACE COARSE FRAGMENTS: Very few cobbles, subrounded basalt

PROFILE MORPHOLOGY:

CONDITION OF SURFACE SOIL WHEN DRY: Recently cultivated, loose

HORIZON	**DEPTH**	**DESCRIPTION**
Ap1	0 to .16 m	Brownish black (7.5YR3/2) moist; clay loam; few medium pebbles, subrounded basalt; single grain. Clear to-
Ap2	.16 to .34 m	Dark brown (7.5YR3/4) moist; light clay; many medium pebbles, subrounded basalt; single grain. Gradual to-
B21	.34 to .53 m	Dark brown (7.5YR3/4) moist; very few fine faint orange mottles; light clay; many cobbles, subrounded basalt; weak 2-5mm subangular blocky. Gradual to-
B31	.53 to .77 m	Brown (7.5YR4/3) moist; few fine distinct orange mottles, common fine faint yellow mottles; light clay; abundant cobbles, subrounded basalt; weak 2-5mm subangular blocky. Clear to-
B32	.77 to .86 m	Dull yellowish brown (10YR5/3) moist; common fine distinct orange mottles, few fine faint yellow mottles; light clay; common medium pebbles, subrounded basalt; weak 2-5mm subangular blocky.

Laboratory data:

Depth	1:5 Soil/Water			Particle size				CEC	Exchangeable Cations				Moistures		Disp	Total Element		
(m)	pH	EC	Cl	CS	FS	S	C	CEC	Ca	Mg	Na	K	ADM	15mP	Ratio	P	K	S
		mS/cm	%		% @ 105°C				meq/100g soil				% @ 105°C		R1			
0.10	6.9	0.03	0.001	22	10	23	46	30 4	16	14	0.12	0.26	11	25	0.24	###	0.41	0 03
0.30	7.3	0.02	0.001	15	7	17	64	33.4	16	17	0.18	0.17	11.4	30	0.29	0 1	0.21	0.01
0.60	7.5	0.02	0.001	27	11	11	50	40.5	19	21	0.41	0.11	16.8	33	0.35	0.06	0.05	0 01
0.86	7.6	0.02	0.001	36	13	7	41	49.7	24	25	0.51	0.14	14	35	0.44	0.09	0.14	0 01

Bulked surface sample	Org. C (W&B) %	Total N %	Extr. P Acid	Extr. P Bicarb	Rep. K meq%	DTPA extr. Fe	Mn	Cu	Zn
			ppm				ppm		
(0-10cm)	1 7	0.17	345	245	0.7	108	38	2.7	1.5

SOIL TYPE: Lily SUBSTRATE MATERIAL: Unknown colluvia over basalt SITE NO: S6
A.M.G. REFERENCE: 268 100 mE 8 251 500 mN ZONE 55 SLOPE: 2 %
GREAT SOIL GROUP: Yellow earth LANDFORM ELEMENT TYPE:
PRINCIPAL PROFILE FORM: Gn2.42 LANDFORM PATTERN TYPE: Level plain

PROFILE MORPHOLOGY:

CONDITION OF SURFACE SOIL WHEN DRY: Recently cultivated, loose

HORIZON	**DEPTH**	**DESCRIPTION**
Ap1	0 to .13 m	Dark brown (7.5YR3/3) moist; clay loam; massive; very few medium ferruginous nodules. Abrupt to-
Ap2	.13 to .30 m	Brown (7.5YR4/4) moist; clay loam; massive; very few medium ferruginous nodules. Clear to-
B21	.30 to .75 m	Brown (10YR4/6) moist; very few fine distinct red mottles; light clay; massive; few coarse ferruginous nodules. Diffuse to-
B22	.75 to .96 m	Brown (10YR4/6) moist; few fine distinct red mottles; light clay; massive; common medium ferruginous nodules. Clear to-
B23	.96 to 1.28 m	Brown (10YR4/4) moist; common fine prominent red mottles; light clay; massive; few coarse ferruginous nodules. Clear to-
B24	1.28 to 1.52 m	Dark reddish brown (2.5YR3/6) moist; common medium distinct yellow mottles; medium clay; massive; common medium ferruginous nodules. Abrupt to-
B25	1.52 to 1.62 m	Dull yellowish brown (10YR5/4) moist; many medium distinct red mottles; medium clay; massive; few medium ferruginous nodules. Clear to-
B26	1.62 to 1.69 m	Dull yellowish brown (10YR5/4) moist; few medium prominent red mottles, few medium prominent yellow mottles; medium clay; massive; very few medium ferruginous nodules. Clear to-

Laboratory data:

Depth	1:5 Soil/Water			Particle size					Exchangeable Cations				Moistures		Disp	Total Element		
(m)	pH	EC mS/cm	Cl %	CS	FS	S	C	CEC	Ca	Mg	Na	K	ADM	15mP	Ratio R1	P	K	S
					% @ 105°C				meq/100g soil				% @ 105°C				%	
0.10	5.8	0.03	0.001	25	19	13	45	6.97	4.4	2.3	0.06	0.21	5	15	0.35	0.08	0.09	0.03
0.30	5.8	0.05	0 002	23	17	9	53	4.04	1.9	2	0.08	0.06	5 5	15	0.17	0 06	0 08	0.02
0.60	6.2	0.03	0 004	24	15	9	54	2.94	0.5	2	0.38	0.06	4.8	16	0.21	0.07	0.09	0.02
0.90	6.8	0 03	0.003	21	15	13	52	4 46	0 8	3.1	0.5	0.06	3 5	17	0.23	0 09	0.09	0.01
1.20	6.9	0.02	0.003	20	14	13	56	5.5	0 8	3.9	0.76	0.04	3 4			0.1	0.08	0.01
1.50	7.2												3.1					

Bulked surface sample	Org. C (W&B) %	Total N %	Extr. P Acid	Extr. P Bicarb	Rep. K meq%	DTPA extr. Fe	DTPA extr. Mn	DTPA extr. Cu	DTPA extr. Zn
			ppm	ppm		ppm	ppm	ppm	ppm
(0-10cm)	1.5	0.09	5	5	0.22	25	39	1.5	0.2

Appendix 3 Land suitability classification

The suitability of land for individual crops has been expressed by assigning one of five land suitability classes (LSC) to each UMA for each crop. The five classes are defined as follows:

Class 1 Suitable land with negligible limitations. This is highly productive land requiring only simple management practices to maintain economic production with the specified land use.

Class 2 Suitable land with minor limitations which either reduce production or require more than the simple management practices[1] of class 1 land to maintain economic production with the specified land use.

Class 3 Suitable land with moderate limitations which either further lower production or require more than those management practices of class 2 land to maintain economic production with the specified land use.

Class 4 Marginal land which is presently considered unsuitable due to severe limitations. The precise effects of these limitations on the proposed land use are unknown. The use of this land is dependent upon undertaking additional studies to determine its suitability for sustained production with the specified land use or to determine whether the effects of the limitation(s) can be reduced to achieve production.

Class 5 Unsuitable land with extreme limitations that preclude its use.

Land is considered less suitable as the severity of limitations for a land use increase, reflecting either (a) reduced potential for production, and/or (b) increased inputs to achieve an acceptable level of production and/or (c) increased inputs required to prevent land degradation. The first three classes are considered suitable for the specified land use as the benefits from using the land for that land use in the long term should outweigh the inputs required to initiate and maintain production. Decreasing land suitability within a region often reflects the need for increased inputs rather than decreased potential production. Class 4 is considered presently unsuitable and is used for marginal land where it is doubtful that the inputs required to achieve and maintain production outweigh the benefits in the long term. It is also used for land where reducing the effect of a limitation may allow it to be upgraded to a higher suitability class. Additional studies are needed to determine the feasibility of using this land.

Class 5 is considered unsuitable having limitations that in aggregate are so severe that the benefits would not justify the inputs required to initiate and maintain production in the long term. It would require a major change in economics, technology or management expertise before the land could be considered suitable for that land use. Some class 5 lands however, such as escarpments, will always remain unsuitable for agriculture.

[1] Where more than simple management practices are required, this may involved changes in land preparation, irrigation management, the addition of soil ameliorants and the use of additional measures to prevent land degradation.